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SELECTIVE ANALYTICAL PARTITIONING OF SEDIMENTS TO EVALUATE POTE--ETC(U)  
DEC 76 J M BRANNON, R M ENGLER, J R ROSE

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# DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-76-7

## SELECTIVE ANALYTICAL PARTITIONING OF SEDIMENTS TO EVALUATE POTENTIAL MOBILITY OF CHEMICAL CONSTITUENTS DURING DREDGING AND DISPOSAL OPERATIONS

by

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Final Report

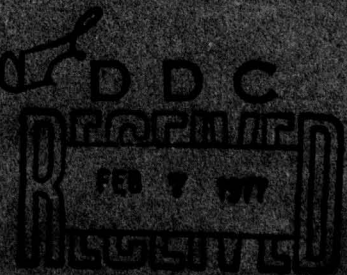
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31 December 1976

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1. The Dredged Material Research Program (DMRP) is a broad, multifaceted investigation of the environmental impacts of dredged material disposal and includes the development of new or improved disposal alternatives. In the early stages of the DMRP's problem definition and assessment and research program development phases, it became apparent that an understanding of the actual pollution potential of dredging and discharging of sediments required substantial state-of-the-art improvement in a number of fundamental aspects. Particularly critical were basic matters of sediment chemistry relating to the physicochemical locations of pollutants or contaminants within the fine-grained and organic sediments. These sediments are often involved in dredging projects and because of contaminant location in the sediment, the availability to the environment to cause water quality and/or biological effects may be variable.
2. Although a several-year-long program of relevant research was developed and initiated, it became apparent that existing and proposed dredged material discharge regulatory guidelines and criteria did not include sampling and analytical techniques that reflected adequately the existing knowledge as to effective ways of assessing environmental impact potential. Provided an opportunity to help direct the criteria development for recently promulgated regulatory programs (Public Laws 92-500 and 92-532), the DMRP recognized the need to initiate immediate short- and intermediate-term efforts to determine the selective partitioning of chemical constituents in sediment in order to evaluate their mobility during dredging and disposal operations and to develop new procedures for even more effective impacts assessment under all environmental conditions. This work unit is a principal effort in that regard.
3. The technical report transmitted herewith represents the results of a laboratory investigation to establish the selective partitioning of sediments to evaluate mobility of chemical constituents during dredging and disposal operations. This study is one of several work units included under Task 1E (Pollution Status of Dredged Material) of the Corps

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of Engineers' DMRP, and in the DMRP's management structure; it is included as part of the Environmental Impact and Criteria Development Project.

4. The basic analytical procedure specified for use in determining the water-column impacts of the aquatic disposal of dredged material pursuant to Public Laws 92-500 and 92-532 is referred to as the standard elutriate test. This report discusses the factors influencing the release of chemical constituents from dredged sediments during the elutriate test procedure and evaluates the interrelationship between the elutriate concentrations and the selective partitioning of the constituents within respective sediment phases. The report further evaluates the effectiveness of the elutriate test in comparison with extractants that remove other sediment phases, and it contrasts the results with those obtained from bulk sediment analysis. The sediment partitioning protocol contains those phases functionally derived to be the interstitial water, the ion exchangeable phase, easily reducible and moderately reducible phases, organic and sulfide phases, and a residual phase. These phases or partitions are listed in decreasing order of mobility and availability for environmental harm.

5. Sediments used for this investigation originated from freshwater and estuarine harbor areas in Ashtabula, Ohio; Mobile Bay, Alabama; and Bridgeport, Connecticut. They represent a wide range of contaminant concentrations, organic and inorganic carbon contents, and physical characteristics. The partitioning of chemical constituents in these sediments has shown the concentrations of trace metals and nutrients in the standard elutriate to be statistically correlated in the majority of cases with their respective concentrations in the interstitial water, exchangeable, and easily reducible phases. The toxic heavy metal or nutrient concentrations in the standard elutriate therefore represent that sediment phase thought to be most mobile and biologically available to the aquatic environment. No relationship existed between toxic heavy metal concentrations in the standard elutriate and "total" or "bulk" metal concentrations of the sediments. This holds true even though some sediments were apparently highly contaminated with some toxic metals with respect to total metal concentrations. This suggests that sediments can be a stable repository for some contaminants.

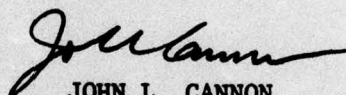
6. It was recommended in this report that the elutriate test and other extractants that define active sediment phases be used to remove the more mobile chemical constituents in order to evaluate long-term mass release of contaminants from sediments following aquatic disposal. It was further recommended that chemical extractants to predict pollution potential of sediments should be selected on their ability to remove mobile or active sediment phases. Elements bound in immobile phases that can be removed only by a total or bulk analysis are unlikely to be chemically or biologically active.

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7. The information and data published in this report are contributions to the further understanding of the complex nature of sediment, water, and chemical/biological interactions and establish a baseline from which to develop meaningful regulatory criteria. It is expected that the methodology employed in this study and the resultant interpretation of the chemical interactions will be of significant value to those persons concerned with CE dredged material permit programs.



JOHN L. CANNON  
Colonel, Corps of Engineers  
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among sediment phases of various stability and mobility. The effect of these sediment fractions or extractable phases upon water quality as indicated by the standard elutriate test and the relation of elutriate concentrations to these fractions was thoroughly investigated. The sediment chemical partitions studied in the selective extraction procedure were those dissolved or in solution in sediment interstitial water; sorbed on sediment mineral and organic material (exchangeable); occluded, co-precipitated, or bound within iron and manganese oxide and hydroxide partitions; bound in organic matter as complexes and compounds precipitated as sulfide salts; and occurring as an extremely stable residual partition in mineral crystalline lattices.

Results of the sediment partitioning fractionation scheme showed that these operationally or functionally defined phases in a sediment could be isolated with good elemental mass balance and precision among the phases. This procedure was used on marine, estuarine, and freshwater sediments. Correlation between standard elutriate test concentrations of chemicals and their concentrations in the various phases or partitions of the selective extraction procedure revealed that the standard elutriate test concentrations represented the sediment phases thought to be most mobile and biologically available in the aquatic environment. The physicochemical form of sediment-bound metals was a much greater factor than the total or bulk metal concentration in determining the mobility of metals into the standard elutriate. In no case were trace metal concentrations in the standard elutriate test or other mobile sediment partitions correlated with total (bulk) metal concentrations in the sediment, although total Kjeldahl nitrogen (TKN) was slightly related to ammonium-N concentration in the elutriate test.

Ammonium-N and manganese were released in the elutriate test in significant amounts at all sampling locations. Also, zinc was released in substantial amounts in the Ashtabula and Bridgeport standard elutriate tests. The concentration of iron in the interstitial water and exchangeable phases had a significant inhibitory effect upon the amount of orthophosphate and trace metals released to the elutriate and subsequently into the water column during open water disposal. Sediments low in soluble iron concentrations in the interstitial water and exchangeable phases released greater amounts of orthophosphate and trace metals into the standard elutriate.

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## SUMMARY

One of the present criteria governing the selection of a disposal site for dredged material is the elutriate test. The elutriate test is a short-term leach of dredged material with dredging site water at a sediment-to-water ratio approximating the slurry formed during hydraulic dredging. At the request of the U. S. Environmental Protection Agency (EPA) regional administrator, bulk sediment analysis may be conducted and used as criteria to determine the contamination potential of dredged material. However, use of bulk sediment analyses as criteria to assess the impact of dredging assumes that all forms of each chemical in the sediment have an equal impact on the environment. Many studies have shown that the total concentration of most elements in the sediments is not related to the release of constituents upon resuspension in the water column nor is it related to the availability of soil constituents.

In order to assess the impact of dredged material discharge upon water quality, specifically as reflected by the elutriate test, and to elucidate the form and species of contaminants in sediments, a selective extraction procedure for sediments has been developed. The selective extraction procedure is applicable to marine and freshwater environments, both aerobic and anaerobic, and minimizes disruption or perturbation of the dredged material during sampling, shipping, and handling, thus reducing change in phases or fraction differentiation or change in the chemical nature of constituents due to factors such as air oxidation, drying and grinding, or freezing.

A sediment can conceptually be partitioned into phases or fractions where chemical constituents can be extracted as a function of the analytical procedure and the physicochemical nature of the specific constituent. Quantitative knowledge of the selective distribution of chemicals in dredged material can aid in determining the relative availability of these chemicals to the water column during dredging operations, their availability to biological communities, and their availability to enter into chemical reactions.

### Experimental Methods

The sediments sampled came from freshwater, estuarine, and salt-water environments in Ashtabula, Ohio; Mobile Bay, Alabama; and Bridgeport, Connecticut, respectively. They represented a wide range of contaminant concentrations, organic and inorganic carbon contents, and particle-size distributions. Separation of the sediments into several phases was accomplished under controlled laboratory conditions.

The functionally defined phases of dredged material studied in this selective extraction procedure were those dissolved in interstitial water, adsorbed on sediment material (exchangeable), occluded or coprecipitated with manganese and iron oxide and hydroxide phases (easily and moderately reducible phases), bound with organic matter and sulfides (organic + sulfide phase), and bound in the crystalline mineral lattice (residual phase). Sediment was also subjected to the standard elutriate test to evaluate the correlation of the partitioned chemicals with the elutriate.

### Results

#### Nitrogen and phosphorus in sediments and in the elutriate

Ammonium-N and orthophosphate were found in high concentrations in the interstitial water of the majority of sediments studied. Exchangeable ammonium-N concentrations were high in all the sediments. Ammonium-N in the interstitial water could be immediately available to the water column upon disposal of dredged material. The exchangeable ammonium-N would be more slowly released than interstitial water ammonium-N, but would be expected to desorb to some extent into the disposal site water.

Sediments from all sampling areas released high concentrations of ammonium-N during the elutriate test. Ammonium-N concentration in the standard elutriate was directly related to sediment total Kjeldahl nitrogen (organic +  $\text{NH}_4^+$ -N) concentration and exchangeable phase

ammonium-N concentration and inversely related to the clay fraction.

Orthophosphate release in the elutriate test was mainly dependent upon the iron chemistry of the sediments, for a large portion of the orthophosphate was scavenged from water by the precipitation of ferric oxides and hydroxides. Orthophosphate release in the elutriate test was directly related to its concentration in the interstitial water and inversely related to iron concentration in the interstitial water and exchangeable phases.

Heavy metal selective extraction and elutriate test results

The selective extraction scheme showed good mass balance. Precision was also good as indicated by the low variation between replicate extractions for most metals. Selective extraction has shown itself to be a useful tool for evaluating the ability of contaminants associated with various sediment phases to influence contaminant concentration in the elutriate test.

Iron. Sediment iron was found primarily in the residual and moderately reducible phases (citrate-dithionite extractable). Interstitial water and exchangeable phase iron were present in large amounts in sediments from Ashtabula and Mobile Bay. The precipitation of iron oxides and hydroxides during dredging operations will affect water quality because iron oxides and hydroxides are efficient scavengers of trace metals and orthophosphate. Sediments low in interstitial water and exchangeable iron released greater amounts of trace metals and orthophosphate into the standard elutriate than did sediments high in reduced iron concentration.

Manganese. Manganese showed a more variable distribution pattern than most other metals, especially in the case of easily reducible phase manganese (hydroxylamine hydrochloride extractable). In general, manganese concentrations were highest in the organic + sulfide and residual phases of the sediments. Exchangeable phase manganese was correlated with interstitial water and easily reducible phase manganese, suggesting that all three phases were in equilibrium.

Manganese was released in large amounts into the standard elutriate

in all areas. Manganese release into the standard elutriate was found to be correlated with the available forms of manganese. The mobility of the various forms of manganese into the standard elutriate could be ranked in the order: interstitial water > exchangeable > easily reducible (even though actual concentration increased in the reverse order). This demonstrated that mobility into the standard elutriate was not related to total concentration but to the physicochemical form of the manganese.

Copper. Copper was found mainly in the residual and organic + sulfide phases of the sediments. The organic + sulfide phase increased in concentration as the total copper concentration of the sediment increased. This may indicate that the organic + sulfide phase acts as a sediment sink for copper. The Bridgeport location provided supporting evidence for the sink theory. A high correlation was observed between organic + sulfide phase copper and copper concentration in the overlying water.

Despite the high total copper observed in some areas, copper was not released in significant amounts into the standard elutriate. The apparent mobility of the various phases of copper during the elutriate test could be ranked in the order: interstitial water > easily reducible > organic + sulfide. Actual concentrations increased in the reverse order. Again, this demonstrated that mobility or availability was not related to the phase having the highest total concentration.

Zinc. Zinc presented the most problems during the sediment fractionation procedure due to reagent contamination in the citrate-dithionite extractant (moderately reducible phase). However, the distribution patterns of zinc in sediments were clear. Organic + sulfide phase zinc was predominant in all locations with the other major reservoirs consisting of either the residual, easily reducible, or moderately reducible phases.

Zinc concentrations were high in the standard elutriates of sediments from Ashtabula and Bridgeport. These results were apparently due to oxygen depletion in the site water during the elutriate test procedure. High zinc concentrations in the standard elutriates of sediments

from Ashtabula and Bridgeport were not seen by other workers who controlled the dissolved oxygen status of the site water during the elutriate test procedure. The sediment phases that correlated with changes in the standard elutriate concentrations were organic + sulfide phase and easily reducible phase zinc.

Nickel. Sediment nickel was associated primarily with the residual phase in all locations. Organic + sulfide phase nickel was generally of secondary importance and was correlated with the total organic carbon content of the sediments. However, moderately reducible phase nickel was more important than the organic + sulfide phase in Ashtabula sediments.

Nickel was not released in high amounts in the standard elutriate of sediments from any area. Nickel concentration in the standard elutriate was related to nickel concentration in different phases in each area, listed below in order of decreasing mobility for each area:

Mobile Bay - easily reducible

Ashtabula - organic + sulfide

Bridgeport - organic + sulfide > easily reducible > interstitial water

These relationships demonstrated the complexity of the factors governing mobility of contaminants into the elutriate test, but in general, the more mobile phases had the greatest relationship to nickel concentration in the standard elutriates.

Cadmium. In the Mobile Bay area, sediment cadmium was concentrated mainly in the residual phase, but in sediments from Ashtabula and Bridgeport, the majority of cadmium was found in the organic + sulfide phase. No cadmium release during the elutriate test was observed from any sediment from any area. Cadmium was reduced below background levels in the standard elutriate from Mobile Bay and Ashtabula and remained at background levels only in the Bridgeport standard elutriate.

Arsenic. In all sediments, arsenic was found associated with the iron oxide fraction. Arsenic from this fraction showed no mobility during the elutriate test. Release of arsenic into the standard elutriate was correlated with exchangeable phase arsenic in Ashtabula

dredged material, which was the only location where exchangeable phase arsenic was found.

### Conclusions

Elemental partitioning of constituents in sediments has shown the concentrations of trace metals and nutrients in the standard elutriate to be statistically correlated in the majority of cases with their respective concentrations in the interstitial water, exchangeable, and easily reducible phases. The metal or nutrient concentrations in the standard elutriate, therefore, represent the sediment phases thought to be the most mobile and biologically available in the aquatic environment.

No relationship existed between trace metal concentrations in the standard elutriate and total metal concentrations in the sediment. This held true even though some sediments were apparently highly contaminated with some trace metals with respect to total metal concentrations. This suggested that sediments can be a stable sink or repository for some contaminants.

Trace metals extracted in the moderately reducible phase and bound in mineral lattices were not related to trace metal concentration in the standard elutriate. This occurred despite the fact that the majority of sediment arsenic and nickel, and in some cases iron and copper, were extracted in the moderately reducible and residual phases.

The concentration of reduced iron in the interstitial water and exchangeable phases had a significant inhibitory effect upon the amount of orthophosphate and trace metals released into the standard elutriate. It is anticipated that the same effect would occur in the water column during aquatic disposal.

Zinc, manganese, and ammonia were the only constituents determined in the standard elutriate that exceeded the EPA aquatic life water-quality standards. However, the concentration of any constituent in the standard elutriate does not reflect the dilution that occurs at the dredging and disposal sites.

### Recommendations

The elutriate test reflects the more mobile contaminants in sediments and should continue to be used as a criterion for evaluating open-water disposal of dredged material.

Dissolved oxygen concentrations in the site water during the elutriate test affect the test results. The oxygen content of the elutriate water during the test should be standardized to reflect the oxygenated conditions that usually prevail at dredging and open-water disposal sites.

The elutriate test and other extractants that remove the more mobile sediment phases should be used to evaluate long-term mass release of contaminants from sediments following aquatic disposal.

When investigating the effect of dredged material disposal on water quality, sediment chemical extractants should be selected that remove mobile sediment phases. Elements bound in immobile phases are unlikely to be chemically or biologically active. In addition to the extractants used in this study, an additional extractant is needed to evaluate the concentration of complexed cations in sediments.

A wide range of chemical extractants and sediments should be used when evaluating the mobility of sediment constituents into the standard elutriate. Ammonium-N and manganese released into the standard elutriate should be thoroughly investigated since high concentrations of both were found in the standard elutriate.

Any extracting solution should be tested for low levels of metals before being used. Low metal levels in the extractants can mask low-level release from the sediments.

## PREFACE

This report presents the results of a study conducted to determine the partitioning of various elements on dredged material and their effect on water quality. The investigation was conducted as part of the Corps of Engineers Dredged Material Research Project (DMRP) under DMRP Work Unit 1E04 entitled "Investigation of Partitioning of Various Elements in Dredged Material," Environmental Impacts and Criteria Development Project (EICDP).

The work was conducted during the period July 1973 - August 1975 by the Environmental Effects Laboratory (EEL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The investigation was conducted by Messrs. J. M. Brannon and I. Smith, Ms. J. R. Rose, and Drs. R. M. Engler and P. G. Hunt, Ecosystem Processes Research Branch (EPRB), EEL. The study was under the general supervision of Dr. R. L. Eley, Chief, EPRB, and Dr. John Harrison, Chief, EEL. Drs. J. W. Keeley and Engler served as Project Managers for the EICDP.

Directors of WES during the conduct of this study and preparation of this report were BG E. D. Peixotto, CE, COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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SELECTIVE PARTITIONING OF SEDIMENTS TO EVALUATE MOBILITY  
OF CHEMICALS DURING DREDGING AND DISPOSAL OPERATIONS

PART I: INTRODUCTION

Background

1. In recent years the Corps of Engineers has dredged an average of 290,000,000 cu m of sediment annually from the Nation's waterways. Of this total, approximately 143,000,000 cu m is disposed of in open-water sites. Recently, a trend toward curtailment of open-water disposal of dredged material and use of confined land disposal has developed. The total annual quantity of dredged material readily identified as being placed in containment areas from maintenance dredging activities alone is approximately 58,000,000 cu m.

2. Concern about the effect of dredging on water quality has largely been due to the fear of the unknown and ignorance of the physicochemical nature of sediments. These concerns, coupled with the unknown effect of deposited dredged material on benthic organisms, have been responsible for initiating the trend towards curtailment of open-water disposal. Confined land disposal of dredged material, however, is not free of environmental problems and may represent a more serious hazard to a smaller area.

3. To determine if open-water disposal of dredged material is environmentally acceptable, sediments must be tested prior to the start of dredging operations. The tests used must determine which, if any, chemical components in the sediments are released during dredging or open-water disposal or on a long-term basis after deposition at an open-water disposal site.

Development of Disposal Criteria

4. Bulk sediment analysis and the elutriate test procedures have

been used in the development of dredged material disposal criteria. These two tests give quite different views of the chemical status of sediments. Bulk chemical analysis inventories what is in the sediment while the elutriate test provides information on contaminants that may be released into the water column during dredging and open-water disposal of dredged material. At present, neither test provides the capability of predicting long-term contaminant release from deposited dredged material into the water column or of evaluating the effect of sediment-bound contaminants on benthic organisms. Interpretation of elutriate test results has also been hampered by lack of basic information on the species and forms of contaminants in sediments that affect elutriate test results.

5. To determine the form and species of contaminants in sediments, geochemical partitioning must be conducted on sediments. The partitioning of trace metals in sediments among the various geochemical phases will determine the impact of the metals associated with dredged material upon water quality and benthic organisms when the sediments are dredged. The abundance and distribution of the various geochemical forms of sediment-bound trace metals have, however, not been well documented. Where trace metal partitioning was conducted upon sediments, the procedures used subjected the sediments to drying and grinding prior to chemical fractionation, resulting in a complete loss of sample integrity and redistribution of constituents among the partitions.

6. The need for geochemical partitioning of sediments coupled with the inadequacy of previous sediment partitioning procedures has warranted development of a new selective chemical extraction procedure. The selective chemical extraction procedure is applicable to marine and freshwater environments, both aerobic and anaerobic, and keeps perturbation of the sediment to a minimum, eliminating elemental changes in phases or fraction differentiation due to factors such as air oxidation or drying and grinding.

#### Scope

7. This report presents: (a) results of sequential selective

extraction (partitioning) of freshwater and saltwater sediments and  
(b) an examination of the relationship between trace metal concentrations in the standard elutriate resulting from the elutriate test and those in the various chemically extracted sediment phases.

## PART II: REVIEW OF LITERATURE

8. A sediment consists basically of a liquid and solid phase, the relative amount of each depending upon the nature (particle-size distribution, organic carbon content, etc.) and degree of compaction of the sediments. In general, the percent solids in a sediment can be expected to increase with depth due to compaction from the weight of the overlying sediment.<sup>1</sup> The first and most obvious fractionation procedure to use in sediments would be to separate the liquid phase from the solid phase.

### Sediment Liquid Phase

#### Interstitial water

9. The sediment liquid phase, commonly known as the interstitial water,<sup>2</sup> contains elements and contaminants already in soluble form. Elements present in interstitial water may originate in two ways: (a) from water trapped within the accumulating sediment and (b) by liberation into solution from the sediment solid phase through diagenetic mobilization processes such as solution, ion exchange, desorption, etc.<sup>2</sup> The extent to which elements are mobilized is governed largely by the redox potential (Eh) and pH of the sediment, which in turn is controlled by the organic content and oxygen supply of the sediment.<sup>2-4</sup> Organic chelation of metals in sediment interstitial water has also been implicated as a mechanism for stabilization of soluble metal ions under conditions that should cause them to precipitate.<sup>5-7</sup>

10. Extraction methodology used to separate sediment interstitial water from the sediments will have a pronounced effect on the metal and nutrient concentrations of the interstitial water. Poldoski and Glass<sup>8</sup> compared anaerobic and aerobic methods of interstitial water extraction. Their results indicated that iron (Fe), manganese (Mn), and phosphorus (P) concentrations in interstitial waters were greatly reduced where anaerobic integrity of the samples was not preserved during interstitial water extractions. Bray et al.<sup>9</sup> found that oxidation of interstitial

waters from anoxic sediments during processing decreased the inorganic phosphate concentration of interstitial waters rich in Fe(II). In addition to removing phosphate from interstitial waters, iron oxides and hydroxides formed during oxidation of Fe(II) rich pore waters will also adsorb trace metals.<sup>10-12</sup>

11. Heat produced by squeezing sediments to obtain the interstitial water or allowing the sediment to warm during storage can result in enrichment of the interstitial water by shifting the ion-exchange equilibria.<sup>13</sup> Bischoff et al.<sup>14</sup> found that warming samples of marine sediments to room temperature prior to extraction of interstitial water resulted in potassium ( $K^+$ ) and chloride ( $Cl^-$ ) enrichments and manganese ( $Mg^{+2}$ ) and calcium ( $Ca^{+2}$ ) depletion in interstitial waters. This temperature effect on sediments coupled with the effect of oxidation on sediment interstitial waters points out the need for sediment refrigeration (without freezing) after sampling and extraction of interstitial waters under anoxic conditions.

12. The Eh and pH conditions in sediments usually result in the occurrence of higher metal and nutrient concentrations in the interstitial water than occurs in the overlying water. Duchart et al.<sup>15</sup> attributed the enrichment of trace metals in interstitial waters to the burial of Fe and Mn oxides in sediments. Subsequent reduction of the Fe and Mn oxides released adsorbed trace metals, increasing their concentration in the interstitial water. Brooks et al.<sup>16</sup> found higher trace metal concentrations in the interstitial waters of reduced sediments than of oxidized sediments. Phosphate concentrations are higher in the water soluble phase of anaerobic soils and sediments than in aerobic soil and sediment systems.<sup>17,18</sup> Patrick and Mahapatra<sup>17</sup> attributed these increases in water-soluble phosphate to the more soluble ferrous form and hydrolysis of phosphate compounds. Ammonium-N also accumulates in anaerobic sediments,<sup>19</sup> being the final product in the anaerobic nitrogen (N) mineralization process.<sup>17</sup>

#### Metal and nutrient migration

13. During dredging sediment interstitial water is mixed with oxygenated water from the dredging and disposal sites. The oxygenated

water from the dredging and disposal site waters will precipitate Fe(II) from the interstitial waters of anaerobic sediments as Fe oxides and hydroxides.<sup>20</sup> Iron oxides and hydroxides efficiently remove trace metals<sup>10-12</sup> and phosphates<sup>9</sup> from solution. Lee,<sup>21</sup> summarizing several papers, concluded that the sorption capacity of hydrous oxides was dependent upon its age, the greatest interaction with heavy metals occurring if the heavy metals were present at the time the hydrous oxides were formed. Sediments high in interstitial water Fe could therefore be expected to release minimal amounts of heavy metals and phosphate during dredging operations.

14. Manganese and ammonium-N are present in high concentrations in the interstitial waters of anaerobic marine and lake sediments. Ho and Lane<sup>22</sup> found ammonium-N concentrations as high as 13.2 mg/l in the interstitial waters of estuarine sediments. Graetz et al.<sup>23</sup> found ammonium-N concentrations as high as 32.6 mg/l in the interstitial waters of lake sediments. Interstitial water Mn concentrations as high as 5.9 and 15.2 mg/l have been reported by Weiler<sup>24</sup> in lake sediments and Duchart et al.<sup>15</sup> in shallow marine sediments, respectively. Manganese(II) is slowly oxidized to insoluble Mn(IV) oxides under aerobic conditions.<sup>20</sup> Ammonium-N is soluble and would be released instantaneously into the dredging site or disposal site water from the sediment interstitial water.<sup>25</sup> Release of Mn and ammonium-N would therefore be expected from sediment interstitial waters into disposal site waters during dredging.

15. Metal and nutrient migration from sediment interstitial waters into the overlying waters is more difficult than metal and nutrient migration within sediments. Metal and nutrient migration within a sediment is controlled largely by ionic and/or molecular diffusion caused by the existence of a concentration gradient between sediment interstitial water and the overlying water.<sup>26,27</sup> When an oxidized surface layer exists, Fe and Mn will precipitate as their relatively insoluble oxides and hydroxides. Lee<sup>28</sup> concluded that migration of dissolved solids such as Fe, Mn, and P from sediments into the overlying water was dependent upon the zone of surface sediment oxidation. Mortimer<sup>29,30</sup> concluded

that chemical exchange from sediments to overlying water was insignificant as long as oxygen concentration at the sediment interface remained above 1 to 2 mg/l. Fillos<sup>31</sup> and Fillos and Molof<sup>32</sup> found that as long as residual oxygen concentration remained above 2 mg/l, the nutrient flux from sediments to the overlying water was reduced. Lee<sup>28</sup> concluded that the hydrodynamic factors of mixing exerted a greater control over the transfer of dissolved solids from sediment to the overlying water than molecular diffusion. Chen et al.<sup>33</sup> found metal transport from sediments to the overlying water controlled mainly by the chemistry of the immediately overlying water as well as that of the interstitial water.

#### Sediment Solid Phase

16. The sediment solid phase contains a great majority of contaminants associated with the sediment. A contaminant can exist in many chemical forms in the natural environment and these forms vary from unstable to extremely stable compounds or complexes.<sup>34</sup> The unstable forms are subject to active migration and may range from ionized species to soluble, readily available organic complexes.<sup>5,6,33,34</sup> The stable chemical forms may range from highly insoluble inorganic precipitates, complexes, compounds, and minerals to very nonreactive organic complexes.<sup>5,35-44</sup> These stable and usually nonreactive forms constitute the major fractions of most sediments.<sup>4,6,16,28,29</sup>

#### Distribution of heavy metals

17. Early workers studying the distribution of heavy metals within sediments followed procedures proposed by Goldberg.<sup>10</sup> Goldberg classified marine sediments into a number of components according to their origin. He divided the sources of sediment into five broad categories: (a) the biogenous portion, composed of biological remains including hard, inorganic material as well as organic matter; (b) the lithogenous portion of continental origin that undergoes no change during its residence in the water column; (c) the hydrogenous portion resulting from formation of solid matter in the water column such as

precipitate formation due to chemical solubility products being exceeded; (d) the cosmogenous part derived from extraterrestrial particles; and (e) the atmogenous portion produced in the atmosphere (e.g., formation of beryllium or boron oxides by the cosmic-ray spallation of N).

18. Goldberg and Arrhenius<sup>37</sup> studied the concentration of certain elements in the mineral phases of pelagic sediments and investigated the sources of the components of the deposits using a technique involving the chelating action of ethylenediaminetetraacetic acid (EDTA). They also used a distilled water extraction of wet sediment and considered it representative of the sum of dissolved and weakly sorbed species. The exchangeable ion fraction was investigated using both boiling 3-percent lithium hydroxide (LiOH) and heating to 80°C with N ammonium acetate for 6 hr. In addition to these functionally derived fractions, mechanical separations according to settling velocity, density, and magnetic reaction were performed. The concentrations of constituents associated with the various grain-size fractions were also determined.

19. Goldberg and Arrhenius<sup>37</sup> used wet sediments, but the anaerobic integrity of the samples was not preserved during processing. Chester and Hughes<sup>38</sup> used a fractionation scheme on dried and ground deep-sea sediments. The fractionation scheme involved acid dissolution of micro-manganese nodules, sediment leaching with EDTA,<sup>10</sup> and an acid leach of the <2  $\mu$ m fraction of sediment to differentiate trace metals into fractions incorporated into the sediments from the overlying waters and transported within detrital components. Chester and Hughes<sup>35</sup> found EDTA unsuitable for partitioning trace metals because of its slowness in stripping adsorbed trace elements from clay mineral surfaces. They advocated a combined acid-reducing agent for extracting dried and ground pelagic sediments where the principal authigenic phases are carbonate minerals and/or ferro-manganese nodules. This selective chemical attack gave an estimate of the hydrogenous and/or biogenous fraction of the total trace element content incorporated into these minerals. For sediments with a high clay or siliceous material content, Chester and Hughes<sup>35</sup> selective chemical attack would yield an estimate of trace element content in carbonate minerals (excluding dolomite), ferro-manganese

nodules, Fe oxide minerals, and trace metals adsorbed onto all mineral surfaces. Chester and Hughes<sup>39</sup> applied their selective extraction scheme<sup>35</sup> to dried and ground deep-sea sediments to determine the partitioning of elements in the hydrogenous fraction. The sediments studied contained little or no opal, montmorillonite, or geolite, for the authors felt that any chemical agent that would dissolve opal or montmorillonite would also attack nonauthigenic (not produced in the marine environment) silicates. Calcium carbonate and ferro-manganese phases were selectively leached from these pelagic sediments using a combined acid-reducing agent and dilute acetic acid. They found that the heavy metals partitioned between the two phases changed during the core sedimentary history, due mainly to variation in the particle-size distribution of quartz.

20. Chester and Messiha-Hanna<sup>40</sup> used a combined acid-reducing agent<sup>35</sup> to partition heavy metals in dried and ground North Atlantic sediments into their lithogenous and nonlithogenous components. The nonlithogenous fraction consisted largely of Mn, Fe, and ferro-manganese oxides, biologically extracted carbonates, and trace elements adsorbed onto all mineral surfaces. The lithogenous fraction was considered the residue after treatment with the combination acid-reducing agent.

21. Piper<sup>41</sup> treated dried and ground sediment from an anoxic Norwegian fjord with 0.1-M HCl to separate the fraction of each constituent incorporated in the sediment from the overlying water. He hoped to solubilize the metal sulfides, hydroxides, and loosely adsorbed metal ions without destroying the crystalline mineral structures. He found that the only effect of 0.1-M HCl on clay minerals was to alter partially the montmorillonite in the samples. The residue was considered the biogenous and lithogenous sediment phase. He found the distribution of Fe, cobalt (Co), and zinc (Zn) in the acid-soluble fraction of surface sediments to parallel their distribution in the suspended phase of the overlying water. He also found the major factors affecting the distribution of Fe, Co, Mn, nickel (Ni), and copper (Cu) in the sediments to be the mineralogy of the lithogenous material and the abundance of organic matter. Zinc was exceptional, with the bulk apparently

derived from the water column by inorganic chemical processes.

22. Nissenbaum<sup>36</sup> studied the mineralogical phase and chemical form in which trace elements occurred in the sediment in order to determine the diagenetic fate of sediment trace metals. He leached dried and ground sediment successively with water, hydrogen peroxide, acetic acid, and HCl and fused the residue with sodium carbonate. Nissenbaum found a decrease in metals concentration from the fraction leached by acetic acid and a subsequent increase in metals concentration in the HCl leachable fraction with increasing depth. He attributed this transfer to diagenetic processes such as recrystallization of amorphous iron-manganese oxides and the transformation of clays.

23. Recent studies have looked at the mineral association of the trace elements. Presley et al.<sup>5</sup> subjected dried and ground sediments to selective chemical attack with dilute acid and hydrogen peroxide solution to determine where redistribution and mobilization of heavy metals had occurred in sediments. They found the concentration of transition and base metals in the sediments to be dependent on the source of the detrital minerals and the biogenic components (skeletal tests or organic compounds). Little evidence was found for the removal of these elements from the water column at the sediment-water interface. They found diagenesis within the sediment column to be possibly time dependent, with the mobilization of some elements, particularly Cu, Fe, Ni, and Zn, from the insoluble silicate phase into the water-soluble phase, suggesting organic complexing. Holmes et al.<sup>42</sup> used a combined acid-reducing agent<sup>35</sup> to study the metal-mineral association of Zn and cadmium (Cd) in dried and ground Corpus Christi Bay sediments. They concluded that the Zn and Cd concentrations were a result of the interactions between the waters of the harbor and the bay, occurring predominantly in winter and resulting in a significant transfer of metals previously deposited on the bottom into the bay.

#### Fractionation procedures in soils

24. Agricultural scientists have also taken an interest in the fractional distribution of heavy metals in soils. Bascomb<sup>43</sup> used potassium pyrophosphate to separate hydrous amorphous oxides of Fe and

organic matter from soils without removing the Fe from crystalline ferric oxides. McLaren and Crawford<sup>44</sup> developed a method for fractionating soil Cu. Their scheme distinguished five fractions of soil Cu: soil solution and exchangeable (0.05-M  $\text{CaCl}_2$  extractable), weakly bound to specific sorption sites (acetic acid extractable), organically bound (potassium pyrophosphate extractable), occluded by free oxides (acid oxalate extractable), and residual (hydrofluoric acid extractable). Copper was found to be mainly associated with the residual and organic phases. Gotoh and Patrick<sup>3,4</sup> used 1 N ammonium acetate whose pH was adjusted to the pH of the soil to extract water soluble + exchangeable Mn and Fe from anaerobic soil suspensions. They carried out the 1 N ammonium acetate extractions under a N atmosphere to avoid Fe precipitation. Gotoh and Patrick<sup>3,4</sup> then extracted reducible Fe and Mn using the method of Mehra and Jackson:<sup>45</sup> a citrate-dithionite extractant buffered with sodium bicarbonate. Following extraction of the reducible phase, residual Mn and Fe were extracted by digestion of the residue with a mixture of nitric and perchloric acids.<sup>3,4</sup> Chao<sup>46</sup> used acidified hydroxylamine hydrochloride to extract Mn oxides from dried and ground soils. A number of workers<sup>45,47,48</sup> have also used various modifications of citrate-dithionite solutions to extract Fe oxides from dried and ground soils.

25. In all the previously mentioned sediment or soil partitioning studies, with the exception of the work of Gotoh and Patrick,<sup>3,4</sup> the procedures used subjected the sediment to drying and grinding or failed to preserve anaerobic integrity prior to chemical fractionation, resulting in a complete loss of sample integrity and redistribution of constituents among the partitions. The oxidation and physical alternation of the sediment during drying and grinding causes phase or fraction differentiation and redistribution of trace metals within the sediments.<sup>33</sup> The authors of this report believe that drying and grinding or destroying the anaerobic integrity of sediments prior to processing has largely invalidated the results of previous selective extraction procedures.

#### Chemical/contaminant locations

26. Based on the results of previous sediment extraction

studies<sup>3,4,5,35-44</sup> and a theoretical paper by Keely and Engler,<sup>34</sup> contaminants in the sediment solid phase may be separated into a number of generalized chemical constituent/contaminant locations (or phases) discussed below.

- a. Adsorbed on the surface of charged mineral and organic surfaces. This location is predominated by cations that are sorbed onto negatively charged ion-exchange sites on clays, onto Fe and Mn oxide phases, and onto negatively charged organic particulates. This phase is in equilibrium with the water-soluble phase,<sup>49</sup> and the ions are readily sorbed or desorbed when the salinity changes or when the concentration of the respective cations changes in the water-soluble phase.<sup>50</sup> The chemical forms found in this location may affect water quality during dredging and disposal operations because they can mobilize to some extent when the dredged material is mixed with water.<sup>25</sup>
- b. Oxides, hydroxides, and hydrous oxides of Mn and Fe that exist as particulate coatings or discrete particles. This sediment phase, commonly known as the reducible phase, will dissolve to some extent under reducing (anaerobic) conditions or form relatively insoluble precipitates in the form of insoluble hydrous oxide precipitates under oxidizing (aerobic) conditions.<sup>3,4,12</sup> These hydrous oxides have a high surface area and readily scavenge trace metals and phosphate by coprecipitation or sorption.<sup>9,10,11,12,25</sup>
- c. Chemical bound in organic matter. This phase contains many chemical compounds and complexes that vary in stability from immediately mobile, easily decomposable, moderately decomposable, to resistant to decomposition.<sup>49</sup> Potential release from this phase into dredging and/or disposal site water would depend on the portion of the organic phase that could be leached. The rate of decomposition and subsequent release of dissolved species at the disposal site depends upon the composition of the organic matter and the intensity of bacterial activity.<sup>51</sup>
- d. Chemicals bound with sulfides. This phase is usually extracted concurrently with the organic phase. In marine sediments this phase may tie up a substantial amount of contaminants such as Fe, Zn, Cu, lead (Pb), mercury (Hg), and Cd that form highly insoluble and relatively stable sulfide compounds in soils and sediments where reducing conditions are intense and sulfide is present.<sup>42,51-56</sup> Some oxidation of metal sulfides will occur during dredging and disposal operations, releasing trace metals that will be rapidly removed from solution by sorption on charged particles, organic matter, hydrous metal oxides, and precipitation reactions.<sup>10,11,12,57</sup> At the disposal

site, reduction will rapidly reestablish a stable, unavailable sulfide phase.

- e. Residual phase (bound within the crystalline lattice of sediment particles). This phase is the major location of a great number of chemical species in the sediment.<sup>5,33,58</sup> These constituents can be released to solution only under chemical conditions vigorous enough to destroy the crystalline structure of the mineral lattice. These constituents are essentially unavailable in the sedimentary environment.<sup>59</sup>

#### Bulk Chemical Analysis and the Elutriate Test

27. Bricker<sup>59</sup> reviewed the handling and preparation of dredged material samples prior to analysis and concluded that the presence of a constituent in sediment is not necessarily an indication that any environmentally adverse effects will be produced by dredging that sediment. The toxic material may be present in a form that makes it completely unavailable chemically and biologically. For this reason, bulk chemical analysis of sediment was not considered a good predictor of potential environmental effects.<sup>59</sup>

28. Lee and Plumb,<sup>25</sup> in a literature review, concluded that dredged material disposal criteria based on bulk chemical analyses are technically unsound because of the assumption that all forms of sediment constituents would have an equal impact on the environment. Windom<sup>60</sup> investigated the water quality aspects of dredging and dredged material disposal in Mobile Bay, Alabama. He concluded that the amount of transfer of chemical constituents from sediments to water is not dependent upon bulk analyses in any simple, readily discernible manner.

29. The elutriate test<sup>34</sup> was developed jointly by the Environmental Protection Agency (EPA) and the Corps of Engineers (CE) to remedy the pronounced inadequacy of bulk chemical analyses to evaluate water-quality alterations during and after dredging operations. The elutriate test consists of mixing dredged material and unfiltered composite disposal or dredging site water in a volumetric 1:4 ratio of dredged material:disposal site water. The flask containing the mixture is stoppered tightly with a noncontaminating stopper and shaken vigorously on a mechanical shaker

for 30 min. After shaking, the suspension is allowed to stand for 1 hr, centrifuged, then filtered through a 0.45- $\mu$  membrane filter to give a clear final solution (the standard elutriate).<sup>34</sup>

30. After an extensive literature review, Lee and Plumb<sup>25</sup> concluded that the elutriate test represented a potentially valuable tool that could provide the information needed to assess the release of contaminants to the water column at a dredging or disposal site. They identified the solid-liquid ratio, time of contact, pH, dissolved oxygen (DO) concentration, agitation, particle size, handling of solids, characteristics of water, and solid liquid separation as factors in the elutriate test that could influence test results. Lee et al.<sup>61</sup> investigated the operating parameters that could affect elutriate test results and found elutriate test results to be most sensitive to the oxygen content of the disposal water. O'Connor<sup>62</sup> also investigated the elutriate test. His data indicated that elutriate test results depended upon the oxygen status of the site water during the test. Oxygenated water resulted in the formation of Fe oxides that adsorbed trace metals. Lee et al.<sup>61</sup> recommended ensuring that aerobic conditions were present in the elutriate test during the agitation period to overcome problems associated with oxygen depletion in the site water during the test procedure. Bricker<sup>59</sup> reviewed the various methods of extracting metals from sediments and concluded that the elutriate test provided the most realistic assessment of the effect of dredged material on the quality of the water column at the disposal site.

31. The physicochemical form of sediment-bound metals may provide more information on the potential environmental impact of sediments than either the elutriate test or bulk chemical analyses. Luoma and Jenne<sup>63,64</sup> found that the biological availability of sediment-bound trace metals and the degree of desorption of metals from sediment to seawater varied with the physicochemical form of the bound metal. These workers reported that under conditions where metal concentrations reach equilibrium between sediments and bottom waters, desorption of sediment-bound trace metals will control the relation between bioavailability and metal-sediment binding stability.<sup>64</sup> Luoma and Jenne<sup>63</sup>

found no detectable uptake of  $^{109}\text{Cd}$  by clams through ingestion of either labeled organic detritus or particulate hydrous-Fe oxide that had been coprecipitated with the nuclide and coated with organic material. However, Ag, Co, and Zn were all taken up by the clams from detrital organics.<sup>64</sup> Uptake of  $^{109}\text{Cd}$  was observed when clams were exposed to either hydrous-Fe oxide particulates lacking the organic coating or San Francisco Bay sediment labeled with the nuclide.<sup>63</sup> Little Zn or Co uptake by clams was observed when those metals were coprecipitated with amorphous Fe oxides or Mn oxides.<sup>64</sup> Chen et al.<sup>33</sup> conducted sediment fractionation of sediments exposed to long-term oxidizing and reducing conditions. They observed that the partitioning of trace metals had been altered in the surface sediments, which indicated that metal partitioning among sediment phases is responsive to environmental conditions.

### PART III: EXPERIMENTAL METHODS

#### Sampling Areas

32. The first area sampled was the Arlington Ship Channel in Mobile Bay, Alabama, a brackish estuarine area. The locations of the three areas sampled are shown in Figure 1.

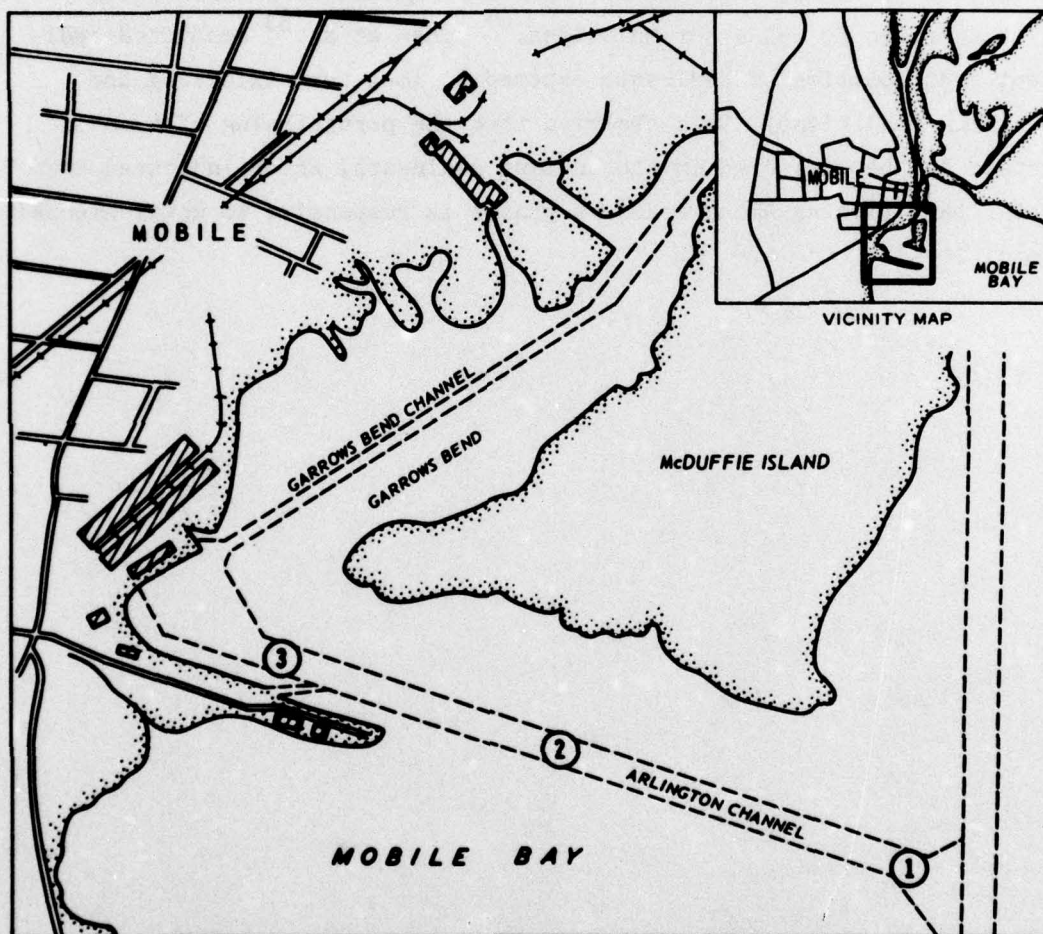


Figure 1. Map of the study area, Mobile Bay, Alabama

33. The second area sampled was Ashtabula Harbor, a freshwater area located in northeast Ohio on the south shore of Lake Erie. The general locality and sampling areas are shown in Figure 2. The

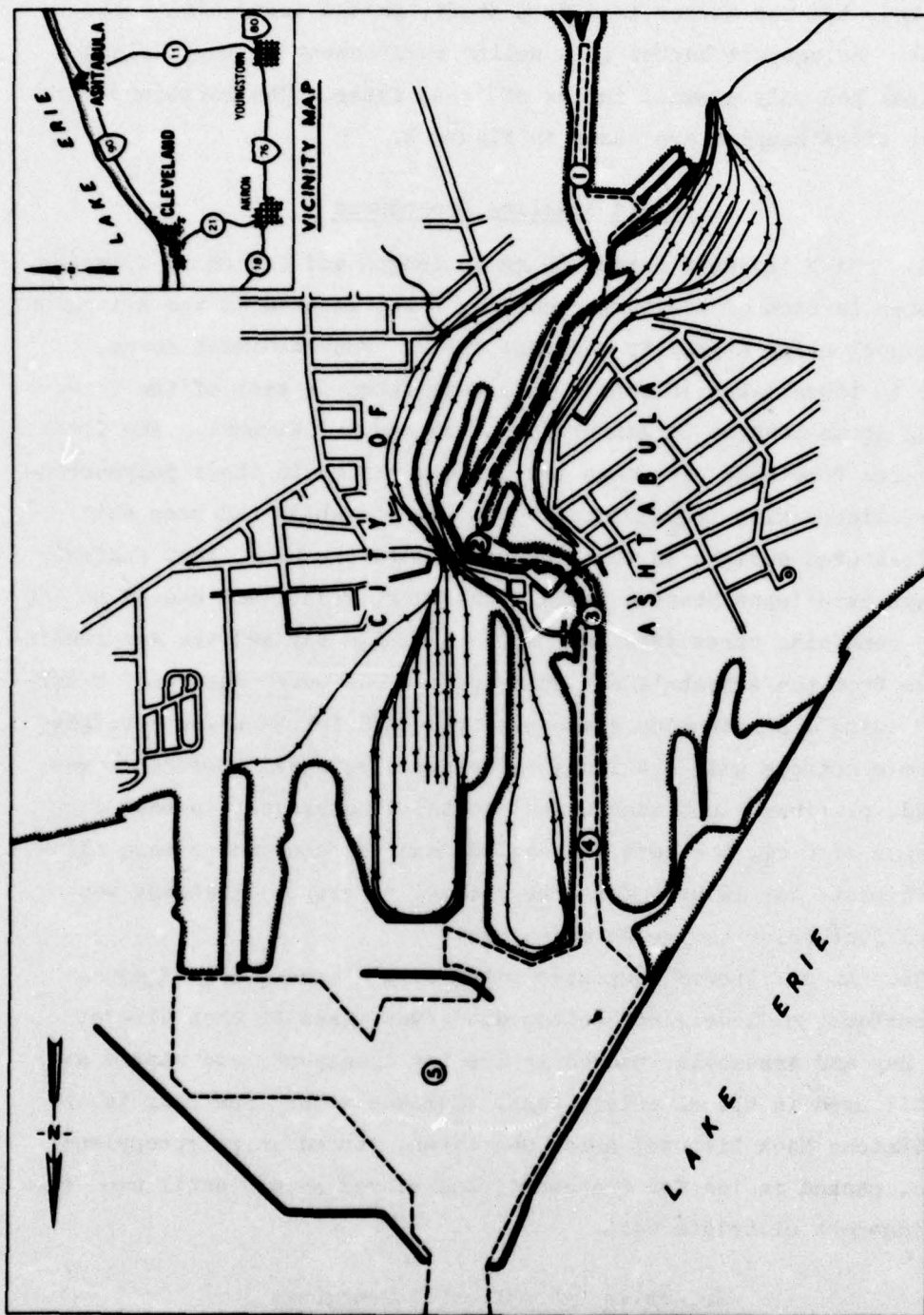


Figure 2. Map of the study area, Ashtabula, Ohio

Ashtabula River Basin has a small drainage area (137 square miles or 220 sq km), but the harbor is a deep draft, inland commercial port.

34. Bridgeport Harbor is a saline environment on Long Island Sound that has only a small influx of fresh water. The locations of the five sites sampled are shown in Figure 3.

#### Field Sampling Procedures

35. Five sediment cores, 60 cm in length and 7.5 cm in diameter, were taken in each of the three sampling sites located in the Arlington Ship Channel using a gravity sediment corer. Four sediment cores, similar to those taken in Mobile Bay, were taken in each of the five sampling sites located in Ashtabula and Bridgeport Harbors. The first three cores from each site were immediately sealed in their polycarbonate core liners with polycarbonate caps (all of which had been acid washed); stored upright in ice; transported to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.; and stored at 4°C. The two remaining cores from each site in Mobile Bay and the one remaining core from the Ashtabula and Bridgeport areas were measured for surface pH using a combination glass electrode and for Eh using a bright platinum electrode with a calomel reference electrode. Before Eh was measured, platinum electrodes were inserted lengthwise into each core to a depth of 6 cm; the core was sealed; and the electrodes were allowed to equilibrate for 12 hr before the calomel reference electrode was inserted just prior to the Eh measurement.

36. An unfiltered composite water sample consisting of equal parts surface, midlevel, and bottom water was taken at each site at Mobile Bay and Ashtabula, packed in ice for transport, and stored at 4°C until used in the elutriate test. Surface water from Long Island Sound (Eatons Neck Disposal Area) was taken, stored in polypropylene bottles, packed in ice for transport, and stored at 4°C until used in the Bridgeport elutriate test.

#### Selective Extraction of Sediments

37. A schematic representation of the selective extraction procedure is presented in Figure 4.



Figure 3. Map of the study area, Bridgeport, Connecticut

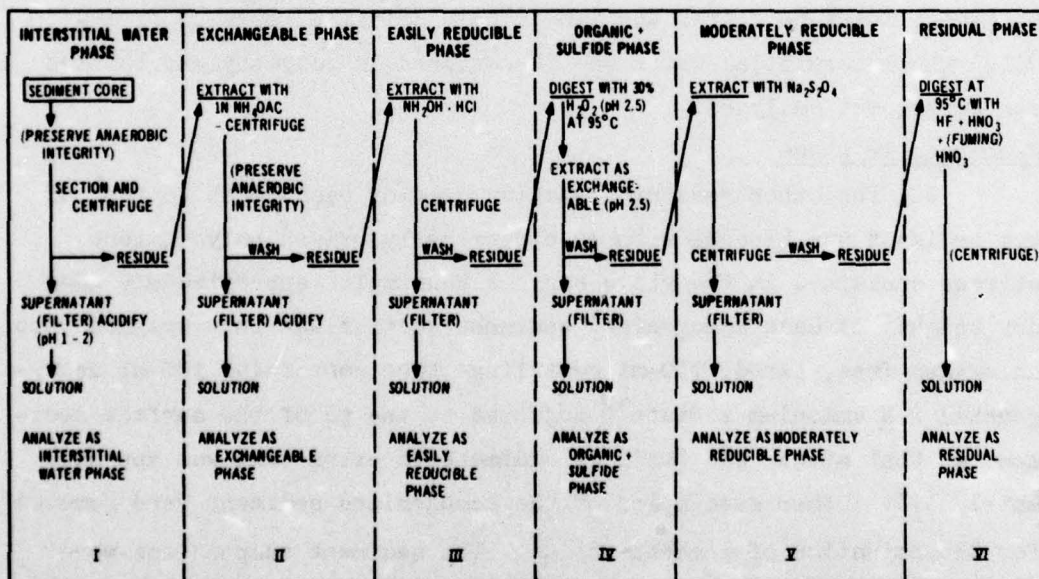


Figure 4. Selective extraction scheme for sediment characterization

38. Prior to sample processing, a disposable glove bag containing a nitrogen atmosphere under positive pressure was prepared. Oxygen-free conditions in the glove bag were verified with a polarographic oxygen analyzer. Sample handling and all steps in the interstitial water and ammonium acetate (exchangeable phase) extractions were conducted under a N atmosphere. All hardware used in the extractions was acid washed in 6 N HCl prior to use.

#### Interstitial water

39. The sediment core was first extruded from its liner into a flat plastic container in the glove bag. The core was then divided into four sections, 15 cm in length. Each section was then split into halves with one half (approximately 300 cc) being used for the interstitial water and the remaining half for all other analyses. The half section used to obtain interstitial water was placed into an oxygen-free, polycarbonate 500-ml centrifuge bottle in the glove bag, followed by centrifugation in a refrigerated centrifuge (4°C) at 9000 rpm ( $13,000 \times g$ ) for 5 min. This was sufficient to obtain approximately 40 percent of the total sediment water. Following centrifugation the interstitial water was vacuum filtered under nitrogen through a 0.45- $\mu$ m pore-size membrane filter and immediately acidified to a pH of 1 with HCl. The interstitial water was then stored in polyethylene bottles for subsequent analyses.

#### Exchangeable phase

40. The other remaining section half of each depth segment of wet sediment was blended with an electrically driven polyethylene stirrer contained in the glove bag. A subsample (approximately 20-g dry weight) of each homogenized sediment section was then weighed into an oxygen-free, tared, 250-ml centrifuge tube containing 100-ml deoxygenated 1 N ammonium acetate<sup>49</sup> adjusted to the pH of the surface sediment at that site. The ratio of sediment to extractant was approximately 1:5. Other subsamples of the homogenized sediment were removed for determination of percent solids. The sediment suspensions were shaken for 1 hr. The suspensions were centrifuged at 6000 rpm for 5 min and then vacuum filtered under oxygen-free conditions. The filtrates

were then acidified and subsequently stored as previously described for the interstitial water. This extractant also included metals and nutrients from the interstitial water. Specific concentrations of constituents in this extract were therefore corrected for the mass of material found in the interstitial water.

41. Additional subsamples from the blended half of the depth segments were set aside for determination of total metals, total Kjeldahl nitrogen (TKN), total organic and inorganic C, total sulfides, and free sulfides.

#### Easily reducible phase

42. The residue from the 1 N ammonium acetate extraction was washed once with 50 ml of N sparged distilled deionized water and centrifuged at 6000 rpm for 5 min, and the liquid phase discarded. The remaining sediment residue was then blended and a 2-g (dry weight) subsample removed and 100 ml of 0.1 M hydroxylamine hydrochloride - 0.01 M nitric acid solution added. The solid-to-extractant ratio was approximately 1:50. The mixture was mechanically shaken for 30 min and then centrifuged at 6000 rpm for 5 min; the extract was then filtered through 0.45- $\mu$ m pore-sized membrane filters.<sup>46</sup>

#### Organic + sulfide phase

43. The residue from the easily reducible phase was washed once with distilled water and centrifuged. The supernate was then discarded. Each of the residue samples was then digested at 95°C with 30 percent hydrogen peroxide acidified to pH 2.5.<sup>49</sup> The digest was kept acidic to keep any metals released in solution. The residue remaining after digestion was mechanically shaken for 1 hr with 100 ml of 1 N ammonium acetate buffered at pH 2.5. The extract was separated as previously described for the easily reducible phase, the residue washed once with distilled water and centrifuged, and the supernate discarded.

#### Moderately reducible phase

44. The washed residue from the oxygen + sulfide phase was extracted with 100 ml of a solution containing 16 g of sodium citrate and 1.67 g of sodium dithionite in H<sub>2</sub>O. The mixture was then mechanically shaken for 17 hr.<sup>47</sup> The extract was separated by centrifugation at

6000 rpm for 5 min and filtration through 0.45- $\mu$ m pore-size membrane filters. This extract contains reduced Fe and metals that may have been associated with the hydrous Fe oxides. The residue was washed once with distilled water and the supernate discarded.

#### Residual phase

45. A 0.5-g (oven-dry weight) subsample of the residue from the moderately reducible phase was digested with a solution of 15 ml of hydrofluoric acid and 10 ml of concentrated nitric acid in a covered Teflon beaker at approximately 175°C. After evaporation to near dryness, 8 ml of fuming nitric acid was added stepwise in 2-ml increments, and the sample was again evaporated to near dryness. The residue was dissolved in hot 6 N HCl and diluted to 50 ml in a volumetric flask. This digestion is a modification of the total digestion method of Smith and Windom,<sup>65</sup> and uses fuming nitric acid in place of perchloric acid.

#### Total Digestion of Sediments

46. The sediment subsample set aside for total metal analyses was dried and ground using an agate mortar. A 0.5-g subsample of sediment was then weighed into a Teflon beaker, digested, and brought to volume in the same manner as the residual phase digestion.

#### Elutriate Test

47. The elutriate test<sup>34</sup> was conducted in duplicate upon each depth segment of one core from each site at a location. The procedure consisted of 30 min of vigorous shaking of one part sediment with four parts dredging or disposal site water (volume/volume), followed by 1 hr of settling and centrifugation and filtration through a 0.45- $\mu$ m pore-size membrane filter.

#### Total Mercury

48. A subsample of each depth segment of each core was analyzed

for total mercury. The analyses were conducted using a Laboratory Data Control U. V. Monitor Model 1235 by the cold vapor method given in "Methods for Chemical Analysis of Water and Waste."<sup>66</sup>

#### Analytical Methods

49. A Perkin-Elmer Model 503 atomic absorption spectrophotometer was used in all metal determinations. Direct flame aspiration with a deuterium arc background corrector was used when concentrations exceeded instrument detection limits. For lower concentrations, extracts were analyzed by the method of standard additions using a Perkin-Elmer Model 2100 heated graphite atomic absorption spectrophotometer. Arsenic (As) was determined using a Perkin-Elmer Model 503 atomic absorption spectrophotometer and a hydride generator. When this method gave poor recovery of spiked samples, the Perkin-Elmer Model 2100 heated graphite atomizer was used.

50. Dispersed particle-size distribution<sup>67</sup> and cation exchange capacity<sup>49</sup> were determined on wet sediment samples from each segment of all cores. The cation exchange capacity procedure included saturating wet sediment samples with ammonium, removing excess ammonium with isopropyl alcohol, and extracting the sediments with a series of 2 N K chloride solutions.<sup>68</sup> Ammonium in the cation exchange extract was determined by nesslerization after steam distillation with Mg oxide.<sup>68</sup>

51. Total organic C was determined by dry combustion.<sup>69</sup> Inorganic C content was estimated by dry combustion without sample pretreatment with sulfurous acid.<sup>70</sup>

52. Total and free sulfides were determined by the Connell<sup>71</sup> modification of the Farber<sup>72</sup> method.

#### Statistical Methods

53. An analysis of variance using a split plot design was run for each parameter studied within each location. Variation was determined between sites in an area, depth within an area, and depth within

a site in an area. Additionally, simple linear correlations were calculated to determine what relationship, if any, existed among the various parameters studied.

## PART IV: RESULTS

### Sediment Physical and Chemical Characteristics

54. Sediments from different areas varied in nearly all physical and chemical parameters measured. Mean values of the physical and chemical parameters measured in the sediments are presented in Table 1. A more detailed examination of sediment physical and chemical characteristics can be found in Appendix A, Tables A1-A3.

55. Results of particle-size analysis indicated that the <2- $\mu$ m particle-size fraction (clay) was predominant in sediments from Mobile Bay, constituting 52.7 percent. Sediments from Ashtabula and Bridgeport were composed predominately of the silt-size fraction (2-50  $\mu$ m), constituting 62.7 percent and 58.2 percent, respectively.

56. Cation exchange capacity was highest in sediments from Mobile Bay, where clay content was highest, averaging 46.3 meq/100 g compared with values of less than 24 meq/100 g in the other two locations.

57. Difference in organic C content between locations was slight. Inorganic C content showed greater differences, averaging 2.19 percent in sediments from Bridgeport compared with 0.07 percent in sediments from Mobile Bay. Total sulfide concentration ranged between 2680  $\mu$ g/g in sediments from Bridgeport and 240  $\mu$ g/g in sediments from Ashtabula. Free sulfides averaging 81  $\mu$ g/g were found in sediments from Bridgeport.

58. Total heavy metal concentrations were different between locations. Sediments from Bridgeport were generally highest in heavy metals with the exception of Mn and Ni. Cadmium and Zn concentrations in sediments from Bridgeport averaged 17.6 and 1067  $\mu$ g/g, respectively. This greatly exceeded concentrations of Cd and Zn in sediments from the other two locations.

59. The temperature, pH, and Eh of the sediments are summarized in Table 2. A more detailed breakdown of the parameters mentioned above can be found in Appendix A, Table A4.

60. Surface temperature varied from 14.9°C in sediments from Bridgeport to 21.9°C in sediments from Ashtabula. The pH measurements

were near neutrality for surface sediments in all areas. The Eh of the surface sediments indicated reduced conditions ( $Eh = < -100$  mV) in all areas.

#### Water Column Characteristics

61. Water column characteristics in the Mobile Bay area during sampling are given in Table 3. Detailed water column data are shown in Appendix A, Table A5. Data were unavailable for sites 2 and 3 due to equipment malfunction. A definite salinity wedge underlying fresh water was evident, reaching a peak of salinity of 13.8 ppt at 7.5 m of water depth. Temperature was fairly constant until more saline water was encountered after which an increase in temperature was noted. Dissolved oxygen averaged 10.9 ppm in the water column; near the sediment-water interface, the DO concentration decreased to 3.6 ppm.

62. Characteristics of Ashtabula surface and bottom waters are presented in Table 3. Detailed water column data are available in Appendix A, Tables A6-A10. Water depth increased as the sampling stations were moved downriver, ranging from 3 m at site 1 to 8 m at site 5. Conductivity and temperature decreased moving downriver and into the harbor. Conductivity and temperature were highest at site 1, reaching values of 2.01 mmhos/cm and 27.4°C, respectively. Site 5, located in the harbor area, showed conductivity and temperature values of 0.32 mmhos/cm and 23.1°C, respectively. Dissolved oxygen concentration was fairly uniform in the water column at sites 4 and 5. Depletion of DO was seen in the bottom waters of the remaining sites. The lowest DO concentration found was 1.37 mg/l in the bottom waters at site 1.

63. Water characteristics of Bridgeport surface and bottom waters during sampling are presented in Table 3. A more detailed presentation of water column data is given in Appendix A, Tables A11-A15. The water depth at the sampling sites varied from 4 to 12 m. Salinity was fairly uniform among sites, averaging 27 ppt. Temperature of the site water was between 14° and 17°C and showed only slight changes with depth, indicating a well-mixed water column. Dissolved oxygen in the water

averaged 7.8 mg/l with no pronounced oxygen depletion in the bottom waters. The water pH was not measured due to equipment malfunction.

64. Nutrient and heavy metal concentrations in the bottom waters at the three locations are presented in Table 4. Nutrient and heavy metal concentrations in waters near the sediment-water interface were not exceptionally high for any location. Copper concentrations ranged from 1 µg/l in Ashtabula waters to 115 µg/l in Bridgeport waters. Zinc was highest in Ashtabula waters, reaching a peak concentration of 20 µg/l. Nickel and Cd were fairly low in Mobile Bay and Ashtabula waters, but reached levels as high as 48 and 4 µg/l, respectively, in Bridgeport waters. Arsenic was low at all areas, reaching a maximum concentration of 1.2 µg/l in the Ashtabula location. Nutrient concentrations were low in Mobile Bay waters. Ammonium-N was high in Ashtabula waters, reaching 258 µg/l. Bridgeport waters were high in ammonium-N and orthophosphate, showing concentrations of 213.2 and 332 µg/l, respectively.

#### Selective Extraction and the Elutriate Test

65. The data presented herein in figures are mean values for each parameter measured at a specific area. Concentrations of all nutrients and metals measured in the selective extraction procedure can be found in Appendix B, Tables B1-B4 (Table B1 gives the key to the abbreviations used in Tables B2-B4). Complete results of site water and elutriate test analyses can be found in Appendix B, Tables B5-B10. Summary tables showing the percent metal extracted in the various chemical phases are given in Tables 5-12 for each metal studied. A more detailed presentation of the percent of each metal extracted in each chemical phase can be found in Appendix B, Tables B11-B31.

66. Details of all statistical operations conducted on the data are given in Appendix C. Tables C1-C7 summarize results of analyses of variance conducted on the data. These tables present F-values and the level of significance for changes between sites in an area, depth within an area, and depth within a site for all parameters measured in the study.

67. Significant correlation coefficients (degree of correlation  $r$ ) are given in Table C8 for the Mobile Bay data, Table C9 for Ashtabula data, Table C10 for Bridgeport data, and Table C11 for all data. The correlation coefficients were obtained using individual numbers, not average values. All correlation coefficients presented are significant at the 0.05 level of probability or higher.

68. All extractions in sediments from Mobile Bay were duplicated to evaluate the precision of the extraction procedures. The coefficient of variation for each metal analyzed in the duplicate extractions is presented in Table C12.

69. When examining these results, or the results of any other selective extraction scheme, the reader should keep a number of points in mind:

- a. Labeling of the various chemically extracted phases is a matter of convenience. Metals extracted in these phases are related in some unknown way to certain forms of chemicals that are expected to be extracted by the reagents used (Personal Communication, Dr. G. Fred Lee, PE, 1975, University of Texas at Dallas, Institute for Environmental Sciences).
- b. Trace metal distribution in any extraction scheme is operationally defined by the method of extraction rather than any fundamental property of the system.<sup>44</sup>
- c. The best approach to sediment fractionation is to analyze separately each mineral phase in the sediment. Sediment chemistry has not advanced to the point where such an approach is feasible. At the present time, the best approach to sediment fractionation is to use an empirical, sequential selective-extraction scheme.

#### Metal Concentrations in Chemically Extracted Phases

##### Iron

70. In sediments from Mobile Bay, the greatest portion of Fe was extracted in the moderately reducible phase. In sediments from Ashtabula and Bridgeport (Figure 5), the majority of Fe was found in the residual phase. The Fe concentration of the residual phase in sediments from Mobile Bay was underestimated due to Fe loss in the wash following extraction of the moderately reducible phase, which contained

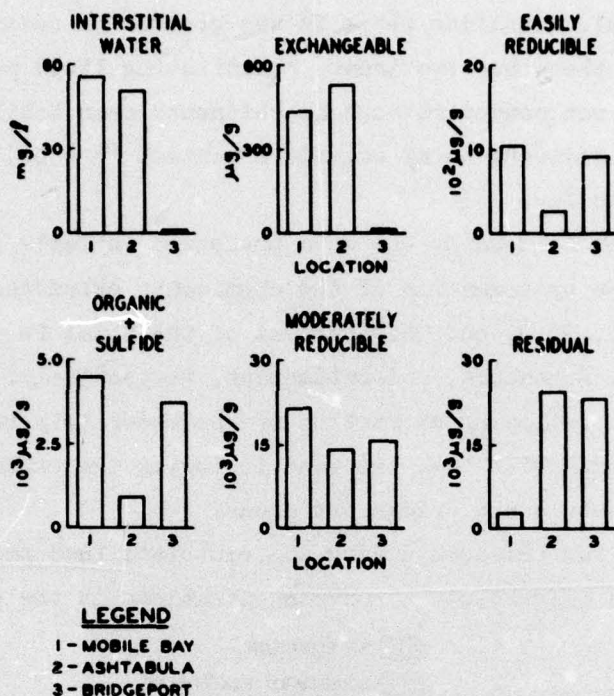


Figure 5. Distribution of Fe in the various chemical fractions

70.46 percent of the Fe extracted in sediments from Mobile Bay compared with 60.91 and 53.90 percent of Fe extracted in the residual phase of sediments from Ashtabula and Bridgeport, respectively (Table 5). The moderately reducible phase accounted for approximately 35 percent of the Fe extracted in sediments from Ashtabula and Bridgeport. In the combined data for the moderately reducible phase, Fe was correlated to a low degree with Mn ( $r = 0.213$ ) and As ( $r = 0.268$ ).

71. Average interstitial water Fe concentrations ranged from 0.31 mg/l in sediments from Bridgeport to 56.2 mg/l in sediments from Mobile Bay. Interstitial water Fe concentrations were correlated with exchangeable phase Fe ( $r = 0.780$ ) and interstitial water Mn ( $r = 0.500$ ) concentrations for all areas.

72. Easily reducible phase Fe concentrations ranged from 291 μg/g in sediments from Ashtabula to 903 μg/g in sediments from Bridgeport. In the combined data for the easily reducible phase, Fe concentrations were correlated with Ni ( $r = 0.500$ ) and As ( $r = 0.303$ ) concentrations.

73. Organic + sulfide phase Fe was greater in sediments from Mobile Bay than the other two areas, constituting 15.52 percent of the Fe extracted. Iron concentrations in sediments from Mobile Bay were correlated with sediment total organic C content ( $r = 0.750$ ) in sediments from Mobile Bay.

74. As can be seen by the data presented in Table 5, the percent of recovery of Fe by summation of the chemically extracted phases accounted for 70.2, 95.9, and 98.4 percent of the total Fe in sediments from Mobile Bay, Ashtabula, and Bridgeport, respectively. Since Fe was lost in the wash following extraction of the moderately reducible phase in sediments from Mobile Bay, the wash following the extraction was deleted for Ashtabula and Bridgeport areas.

75. Iron was released during the elutriate test procedure for all areas tested (Figure 6). Iron concentrations in the standard

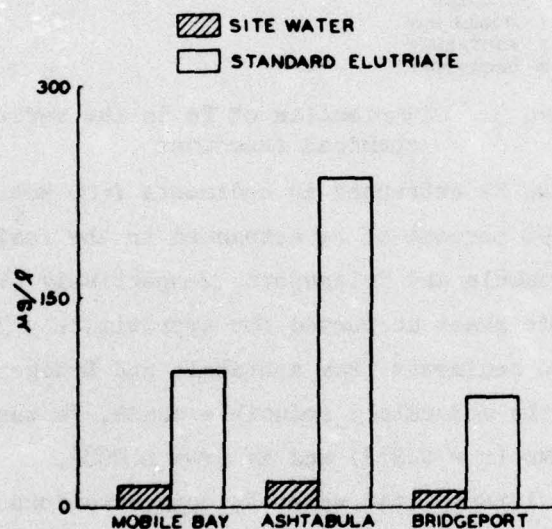


Figure 6. Average Fe concentrations in site waters and in the standard elutriates from three areas

elutriate\* ranged from 79 µg/l in sediments from Bridgeport to 234 µg/l in sediments from Ashtabula. Iron concentrations in the standard elutriate were correlated with interstitial water Fe ( $r = 0.730$ ) and

\* The term "standard elutriate" is used to designate the supernatant resulting from the elutriate test procedure.

exchangeable phase Fe ( $r = 0.665$ ) concentrations in sediments from Mobile Bay. Iron concentrations in the standard elutriate were correlated with easily reducible phase Fe ( $r = 0.513$ ) concentrations in sediments from Bridgeport.

#### Manganese

76. The three areas studied showed different Mn concentrations in each chemically extracted phase. Figure 7 shows the average concen-

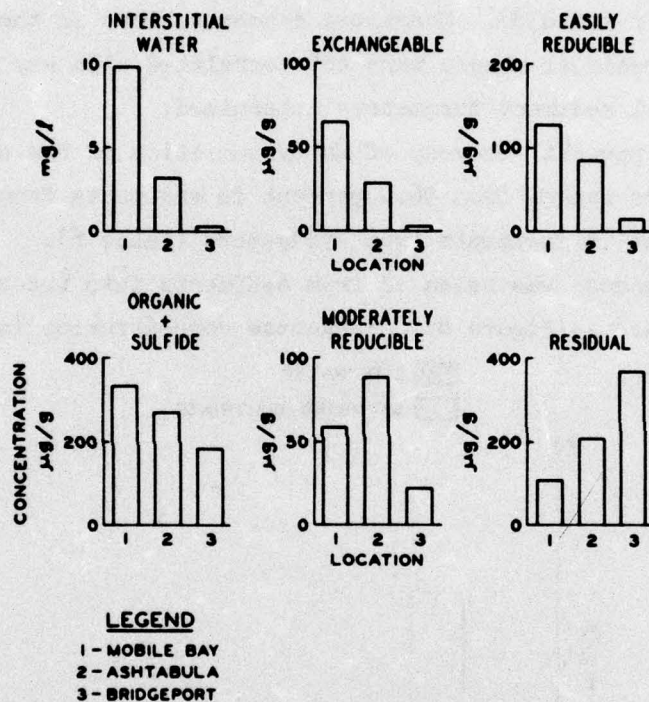


Figure 7. Distribution of Mn in the various chemical fractions

trations of Mn found in the various sediment fractions. The Mn concentrations in the organic + sulfide phase were highest in the Mobile Bay and Ashtabula sediments, averaging 338 and 267  $\mu\text{g/g}$ , respectively. Organic + sulfide phase Mn represented 46.60 percent of the Mn extracted from Mobile Bay sediments and 40.73 percent of the Mn extracted from Ashtabula sediments (Table 6). The concentration of residual phase Mn averaged 363  $\mu\text{g/g}$  in Bridgeport sediments, which was the highest concentration of any phase extracted in that location. Residual phase Mn

constituted 62.89 percent of the total Mn extracted in Bridgeport sediments.

77. Interstitial water Mn concentrations ranged from an average of 9.75 mg/l in sediments from Mobile Bay to an average of 0.29 mg/l in sediments from Bridgeport. The Mn concentrations in the interstitial water were correlated with exchangeable phase Mn concentration ( $r = 0.904$ ) and easily reducible phase Mn concentration ( $r = 0.749$ ). Exchangeable phase Mn was also correlated with easily reducible phase Mn concentration ( $r = 0.838$ ). Manganese concentrations in the moderately reducible and residual phases were not correlated with any of the physical or chemical sediment parameters determined.

78. The percent recovery of Mn by summation of the chemically extracted phases ranged from 96.9 percent in sediments from Mobile Bay to 111.2 percent in sediments from Bridgeport (Table 6).

79. Manganese was released from sediments into the standard elutriate at all areas (Figure 8). Manganese concentration in the standard

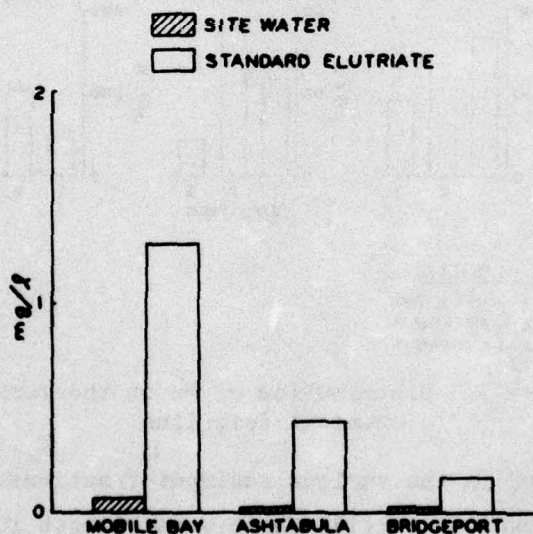


Figure 8. Average Mn concentrations in site waters and in the standard elutriates from three areas

elutriate ranged from an average of 1.28 mg/l in sediments from Mobile Bay to an average of 0.16 mg/l in sediments from Bridgeport. Manganese concentrations in the standard elutriate were correlated with Mn

concentrations in the interstitial water ( $r = 0.849$ ), exchangeable phase ( $r = 0.755$ ), and easily reducible phase ( $r = 0.633$ ).

#### Copper

80. The majority of Cu was found in the residual phase in sediments from Mobile Bay and in the organic + sulfide phase in sediments from Ashtabula and Bridgeport (Figure 9). Residual phase Cu averaged

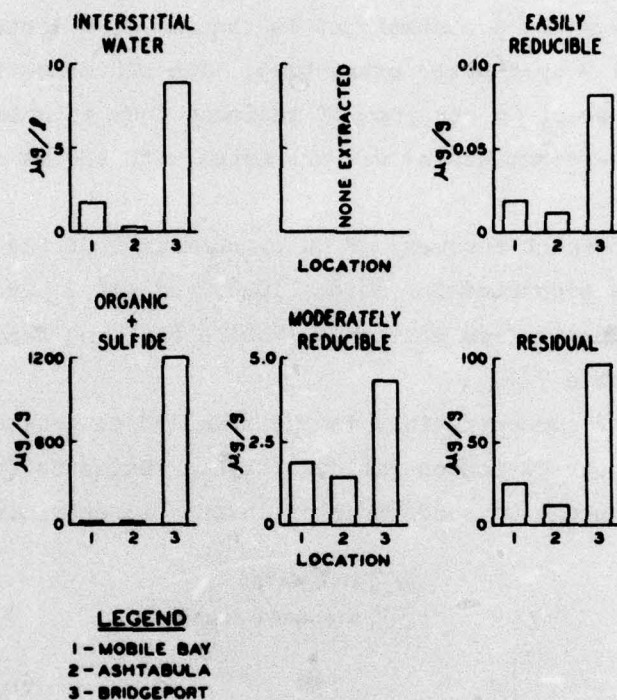


Figure 9. Distribution of Cu in the various chemical fractions

29.4 µg/g in sediments from Mobile Bay, accounting for 59.19 percent of the Cu extracted (Table 7). The organic + sulfide Cu concentration in Ashtabula and Bridgeport sediments averaged 22.2 µg/g and 1255 µg/g respectively. This represented 59.91 and 92.00 percent of the Cu extracted in sediments from Ashtabula and Bridgeport, respectively. Organic + sulfide phase Cu concentrations were correlated with total organic C content ( $r = 0.405$ ) of the sediments. Organic + sulfide phase Cu was also correlated with sediment total sulfide concentration in Ashtabula ( $r = 0.721$ ) and Bridgeport ( $r = 0.677$ ) sediments.

81. Interstitial water Cu concentrations ranged from an average of 0.25  $\mu\text{g}/\text{l}$  in sediments from Ashtabula to 8.92  $\mu\text{g}/\text{l}$  in sediments from Bridgeport. Interstitial water Cu concentrations were correlated with the concentrations of Cu in the easily reducible phase ( $r = 0.372$ ) and the organic + sulfide phase ( $r = 0.603$ ).

82. Copper was not extracted from the sediments by the ammonium acetate extractant. In sediments from Mobile Bay, background Cu concentrations of 60  $\mu\text{g}/\text{l}$  as a contaminant in the ammonium acetate decreased to approximately 3  $\mu\text{g}/\text{l}$  after extraction. The sediments from Mobile Bay removed 0.3  $\mu\text{g}$  of Cu per gram of sediment from solution when 20 g of sediment (dry-weight basis) was extracted with 100 ml of ammonium acetate solution.

83. The percent recovery of Cu by summation of the chemically extracted phases accounted for 88.8, 110.8, and 118.2 percent of the total Cu in sediments from Ashtabula, Mobile Bay, and Bridgeport, respectively (Table 7).

84. Copper concentrations in the standard elutriate exceeded disposal site water Cu concentrations only in sediments from Bridgeport (Figure 10). Average Cu concentration in the standard elutriate ranged

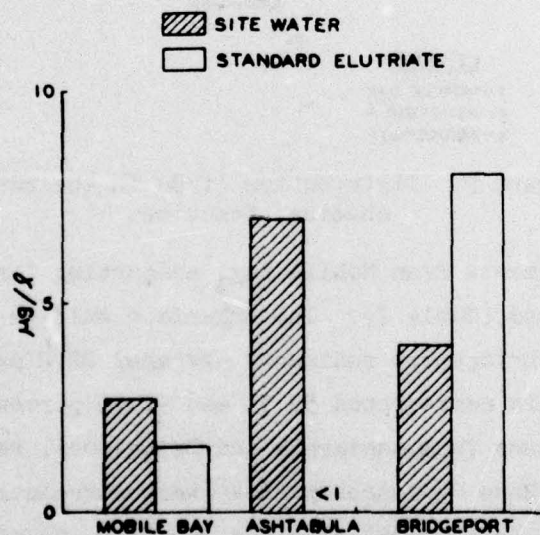


Figure 10. Average Cu concentrations in site waters and in the standard elutriate from three areas

from  $<1 \mu\text{g}/\ell$  in Ashtabula to  $8.02 \mu\text{g}/\ell$  in Bridgeport. Copper concentrations in the standard elutriate were correlated with Cu concentrations in the interstitial water ( $r = 0.551$ ), easily reducible phase, ( $r = 0.416$ ), and organic + sulfide phase ( $r = 0.432$ ).

85. Copper concentrations in the bottom waters of Bridgeport were correlated with Cu concentrations in organic + sulfide phase of the surface sediments of Bridgeport. These results are presented graphically in Figure 11.

#### Zinc

86. The highest Zn concentrations in the phases analyzed occurred in the organic + sulfide phases in all locations (Figure 12): average Zn concentration ranged from  $123.8 \mu\text{g}/\text{g}$  in sediments from Mobile Bay to  $568.0 \mu\text{g}/\text{g}$  in sediments from Bridgeport. This accounted for 54.75 percent of the Zn extracted in Mobile Bay sediments and 56.48 percent of the Zn extracted in Bridgeport sediments (Table 8).

87. Zinc concentrations in the organic + sulfide phase were correlated with total sulfide concentrations ( $r = 0.526$ ) in sediments from Bridgeport. No Zn was extracted in the exchangeable phase of sediments from Mobile Bay. Average Zn concentrations in the interstitial water ranged from  $0.035 \text{ mg}/\ell$  in sediments from Mobile Bay to  $0.92 \text{ mg}/\ell$  in sediments from Ashtabula.

88. Sodium dithionite used in the moderately reducible phase extraction was contaminated with Zn. This Zn contamination carried over into the residual phase, necessitating calculation of Zn concentration in the residual phase by the difference between the analytical total and the sum of the remaining Zn phases. Mass balance could therefore not be calculated for sediment Zn.

89. Zinc was released into the standard elutriate from Ashtabula and Bridgeport sediments (Figure 13). Zinc concentrations in the standard elutriate ranged from  $0.005 \text{ mg}/\ell$  in the Mobile Bay area to  $1.13 \text{ mg}/\ell$  in the Bridgeport area. Zinc concentrations in the standard elutriate were correlated with Zn in the easily reducible phase ( $r = 0.466$ ) and in the organic + sulfide phase ( $r = 0.516$ ).

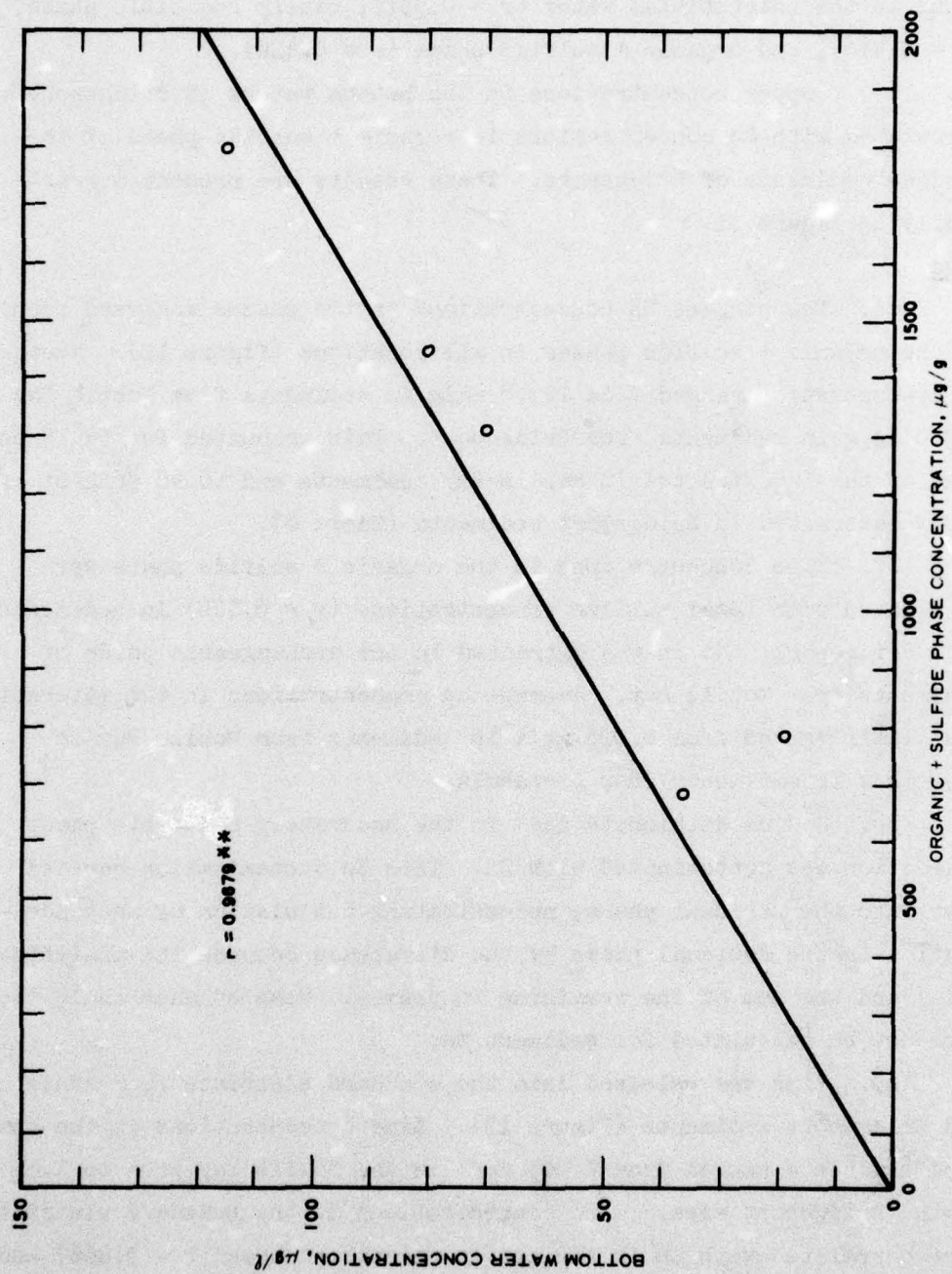


Figure 11. Regression of Cu concentration in Bridgeport bottom waters with copper concentration in the organic + sulfide phase of Bridgeport surface sediments

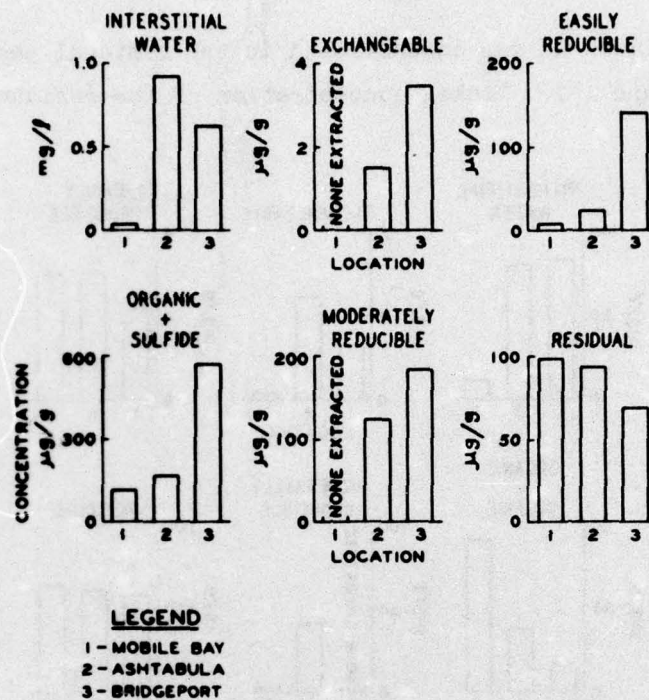


Figure 12. Distribution of Zn in the various chemical fractions

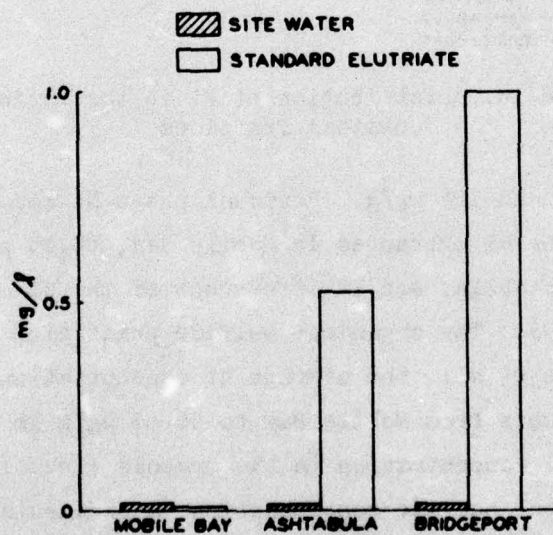


Figure 13. Average Zn concentrations in site waters and in the standard elutriates from three areas

## Nickel

90. Sediment Ni was concentrated in the residual phase at all locations (Figure 14). Nickel concentration of the residual phase

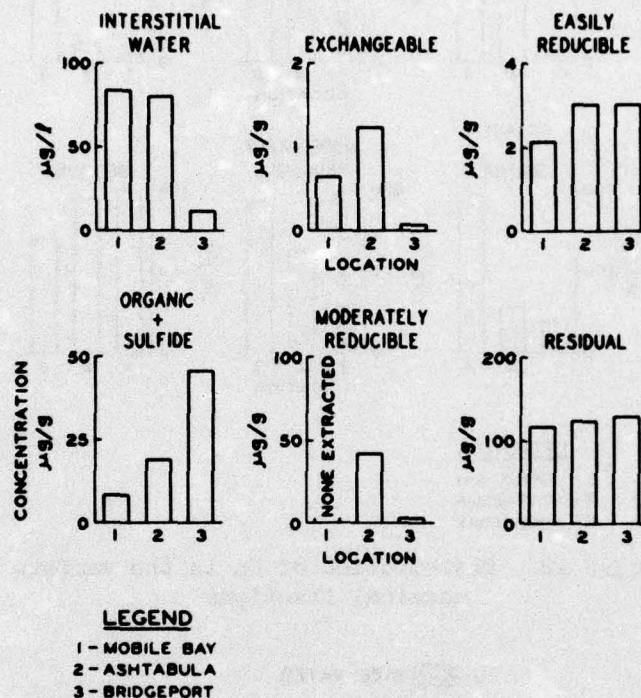


Figure 14. Distribution of Ni in the various chemical fractions

ranged between 116 and 128 µg/g. Residual phase Ni accounted for 91.44 percent of the Ni extracted in Mobile Bay, 66.45 percent of the Ni extracted in Ashtabula, and 72.56 percent of the Ni extracted in Bridgeport (Table 9). The organic + sulfide phase also contained significant amounts of Ni: the average Ni concentration ranged from 8.17 µg/g in sediments from Mobile Bay to 46.65 µg/g in sediments from Bridgeport. Nickel concentration in the organic + sulfide phase was correlated with total sulfide concentration in sediments from Ashtabula ( $r = 0.457$ ) and Bridgeport ( $r = 0.685$ ). Nickel concentration in the organic + sulfide phase of all areas was also correlated with total sediment organic carbon ( $r = 0.418$ ).

91. The percent recovery of Ni by summation of the chemically extracted phases ranged from 81.4 percent in sediments from Mobile Bay to 87.9 percent in sediments from Bridgeport (Table 9).

92. Nickel was released into the standard elutriate by sediments from the Ashtabula and Bridgeport areas (Figure 15). The highest average

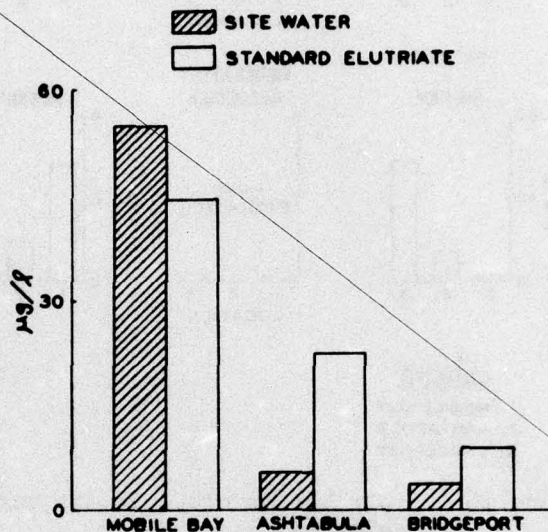


Figure 15. Average Ni concentrations in site waters and in the standard elutriates from three areas

concentration of Ni in the standard elutriate, 44.2 µg/l, was found in the Mobile Bay area where no release of sediment Ni occurred. Nickel concentrations in the standard elutriate were correlated with Ni concentrations in different sediment phases in each location. The sediment phases whose Ni concentrations were correlated with Ni concentrations in the standard elutriate are listed in Table 10 with the degree of correlation.

#### Cadmium

93. Cadmium concentrations in the residual phase were highest in sediments from Mobile Bay, but Cd in the organic + sulfide phase was highest in sediments from Ashtabula and Bridgeport (Figure 16). Cadmium concentrations in the residual phase ranged from undetectable levels (<0.1 µg/g) in sediments from Bridgeport to an average of 2.86 µg/g in

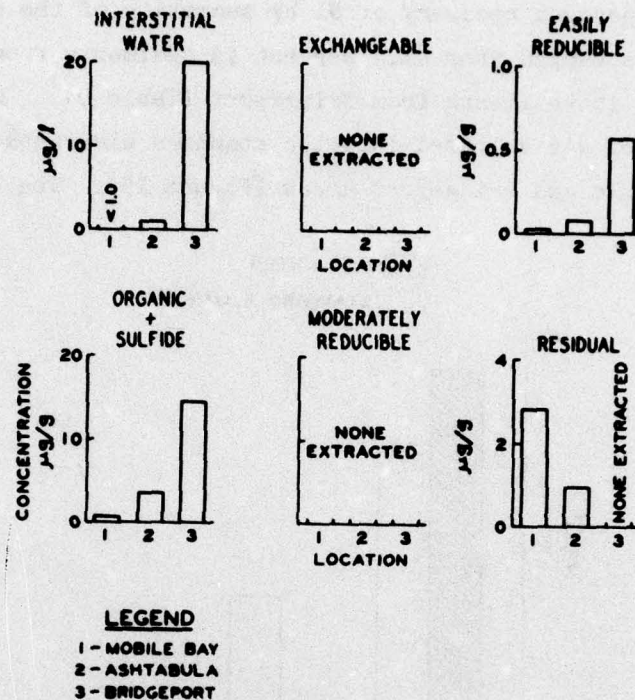


Figure 16. Distribution of Cd in the various chemical fractions

sediments from Mobile Bay. Average Cd concentrations in the organic + sulfide phase ranged from 0.60 µg/g in sediments from Mobile Bay to 14.58 µg/g in sediments from Bridgeport. Residual phase Cd accounted for 81 percent of the Cd extracted in sediments from Mobile Bay (Table 11). Organic + sulfide phase Cd constituted 78.02 percent of the Cd extracted in Ashtabula sediments and 95.68 percent of the Cd extracted in Bridgeport sediments. No Cd was extracted in the exchangeable or moderately reducible phases in any of the sediments. Cadmium concentrations in the organic + sulfide phase were correlated with total sediment sulfide concentrations in sediments from Ashtabula ( $r = 0.512$ ) and Bridgeport ( $r = 0.501$ ).

94. Cadmium percent recovery was good; the summation of the chemically extracted phases accounted for 85.7, 96.7, and 116.5 percent of the total Cd in sediments from Bridgeport, Mobile Bay, and Ashtabula, respectively (Table 11).

95. Cadmium concentrations in the standard elutriate were below instrument detection limits in the Mobile Bay and Ashtabula locations. Cadmium concentrations in the Bridgeport standard elutriate averaged 4.9  $\mu\text{g}/\ell$ , which was equal to background Cd levels in the water used in the elutriate test (Figure 17). No correlation was seen between Cd concentrations in the standard elutriate and Cd concentration in any of the various chemically extracted sediment phases.

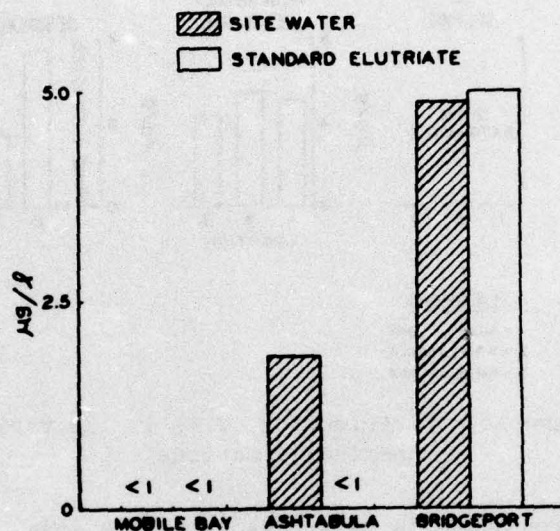


Figure 17. Average Cd concentrations in site waters and in the standard elutriates from three areas

#### Arsenic

96. Arsenic concentrations were highest in the moderately reducible phase of the sediments from the areas sampled (Figure 18); average As concentrations ranged from 4.45  $\mu\text{g}/\text{g}$  in Bridgeport sediments to 5.55  $\mu\text{g}/\text{g}$  in Ashtabula sediments, accounting for 70.44 to 58.77 percent, respectively, of the sediment As extracted in those areas (Table 12). No As was extracted from the organic + sulfide phase in any area. Average As concentration in interstitial water ranged from 4.6  $\mu\text{g}/\ell$  in sediments from Mobile Bay to 34.5  $\mu\text{g}/\ell$  in sediments from Bridgeport. Exchangeable phase As was found only in sediments from Ashtabula and was correlated with interstitial water As ( $r = 0.659$ )

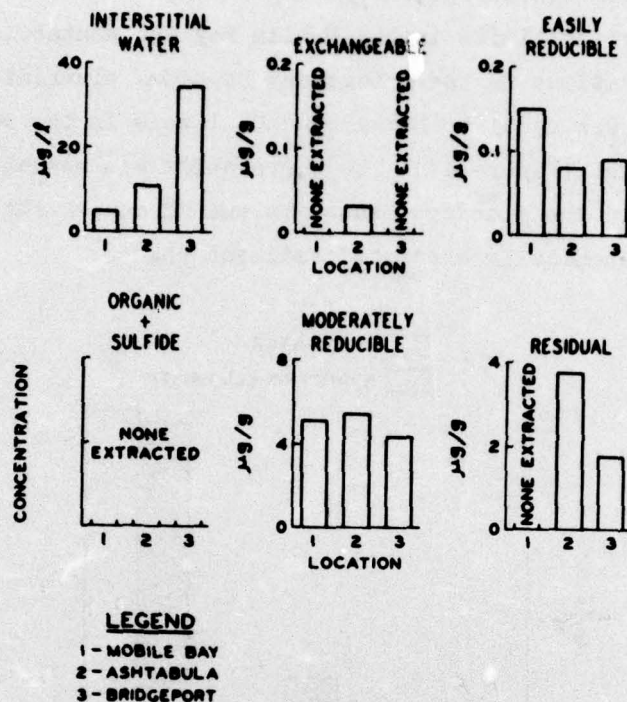


Figure 18. Distribution of As in the various chemical fractions

and easily reducible phase As ( $r = 0.446$ ) in this area.

97. Percent recovery of As by summation of the chemically extracted phases accounted for 90.3, 118.2, and 145.0 percent of the total As in sediments from Bridgeport, Mobile Bay, and Ashtabula, respectively (Table 12).

98. Average As concentration in the standard elutriate ranged from 1.7 µg/l in the Mobile Bay location to 3.32 µg/l in the Bridgeport sediments (Figure 19). Arsenic concentrations in the standard elutriate were correlated with exchangeable phase As ( $r = 0.477$ ) in the sediments from Ashtabula.

#### Mercury

99. Mercury was released to the standard elutriate only in sediments from Bridgeport (Figure 20). Average Hg concentration in the standard elutriate ranged from undetectable levels ( $<0.05$  µg/l) in Ashtabula to 0.63 µg/l in Bridgeport. Mercury concentration in the

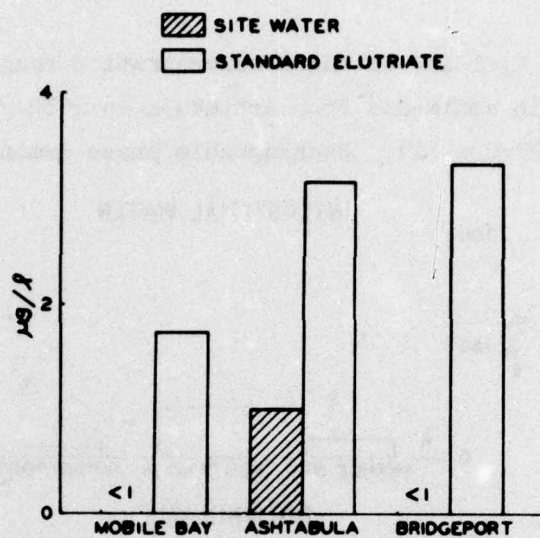


Figure 19. Average As concentrations in site waters and in the standard elutriates from three areas

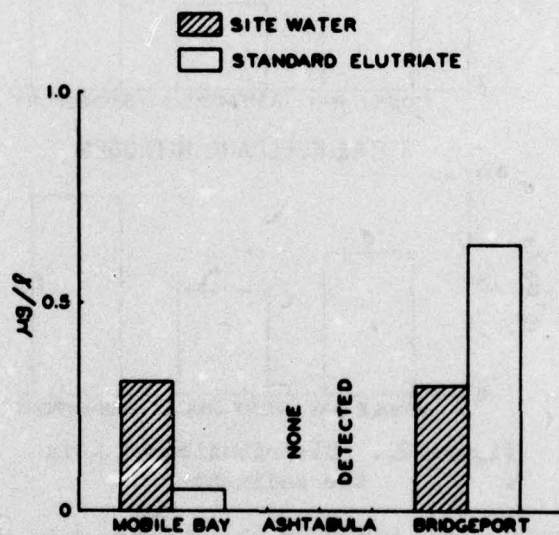


Figure 20. Average Hg concentrations in site waters and in the standard elutriates from three areas

standard elutriate was not correlated with total Hg concentrations in the sediments.

### Nitrogen

100. Total Kjeldahl nitrogen concentration ranged from an average of 1390  $\mu\text{g/g}$  in sediments from Ashtabula to 2680  $\mu\text{g/g}$  in sediments from Bridgeport (Figure 21). Exchangeable phase ammonium nitrogen

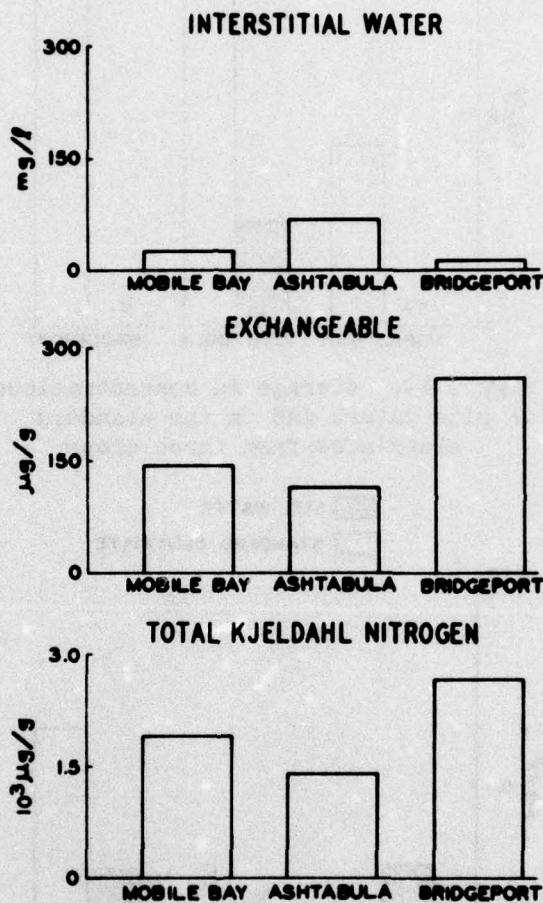


Figure 21. Distribution of N in the sediments

( $\text{NH}_4^+-\text{N}$ ) was a significant portion of the TKN found in the sediments. Average exchangeable phase  $\text{NH}_4^+-\text{N}$  concentration ranged from 113.6  $\mu\text{g/g}$  in sediments from Ashtabula to 257.0  $\mu\text{g/g}$  in sediments from Bridgeport. Ammonium-N in the interstitial water was also found in high concentrations, averaging 63.1  $\text{mg/l}$  in sediments from Ashtabula.

101. The relationship between  $\text{NH}_4^+$ -N in interstitial water and in the exchangeable phase was very site specific; correlations were found in Mobile Bay ( $r = 0.769$ ), Ashtabula ( $r = 0.729$ ), and Bridgeport ( $r = 0.612$ ). No overall correlation existed between interstitial water exchangeable phase  $\text{NH}_4^+$ -N concentrations in surface sediments and  $\text{NH}_4^+$ -N concentrations in bottom waters at the sampling areas.

102. Ammonium-N was released into the standard elutriate in significant amounts at all areas (Figure 22). Ammonium-N concentration

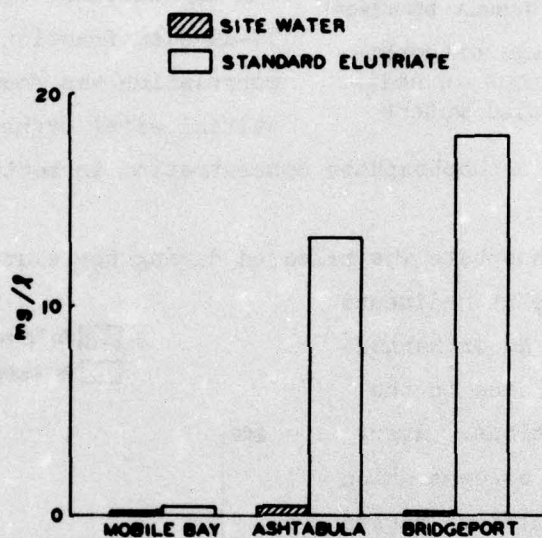


Figure 22. Average ammonium-N concentrations in site waters and in the standard elutriates from three areas

in the standard elutriate ranged from an average of 0.14 mg/l in sediments from Mobile Bay to 18.01 mg/l in sediments from Bridgeport.

103. Ammonium-N concentration in the standard elutriate was positively correlated with exchangeable phase  $\text{NH}_4^+$ -N ( $r = 0.437$ ) and TKN ( $r = 0.464$ ), and negatively correlated with the clay size fraction ( $r = -0.552$ ). Interstitial water  $\text{NH}_4^+$ -N was correlated with  $\text{NH}_4^+$ -N concentration in the standard elutriate only in sediments from Mobile Bay ( $r = 0.799$ ) and Ashtabula ( $r = 0.659$ ).

## Phosphorus

104. Interstitial water orthophosphate showed high concentrations in sediments from Mobile Bay and Bridgeport, averaging 56.1 mg/l and 66.2 mg/l, respectively (Figure 23). Ashtabula interstitial water

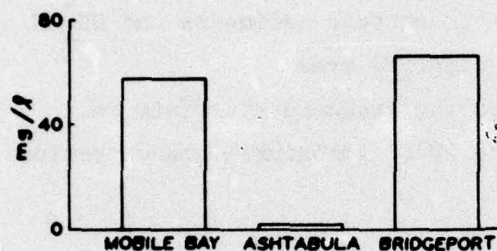


Figure 23. Average orthophosphate concentrations in sediment interstitial waters

showed an average orthophosphate concentration of only 0.4 mg/l. Interstitial water orthophosphate in sediments from Ashtabula was correlated with interstitial water Mn ( $r = 0.533$ ) and the sediment silt fraction (2- to 50- $\mu$ m-diam fraction) ( $r = 0.615$ ). No correlation was found between interstitial water orthophosphate in surface sediments and orthophosphate concentration in bottom waters of the areas sampled.

105. Orthophosphate was released during the elutriate test procedure from Bridgeport sediments only (Figure 24). No orthophosphate release was noted in the two remaining locations. Average orthophosphate concentration in the standard elutriate ranged from <3  $\mu$ g/l in sediments from Mobile Bay to 189 mg/l in sediments from Bridgeport. Orthophosphate concentration in the standard elutriate was positively correlated with interstitial water orthophosphate concentration ( $r = 0.691$ ) and negatively correlated with interstitial water Fe ( $r = -0.667$ ) and exchangeable phase Fe ( $r = 0.705$ ).

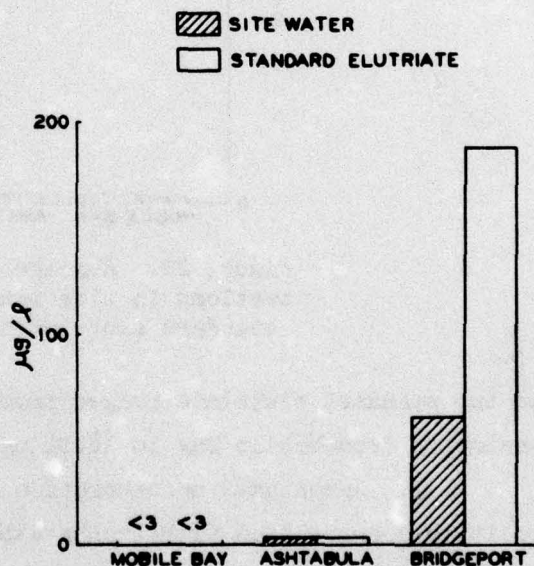


Figure 24. Average orthophosphate concentrations in site waters and in the standard elutriates from three areas

## PART V: DISCUSSION

### Sediment Trace Metal Distribution

#### Trace metal mobilization

106. Sediment interstitial water is the mobile, nonadsorbed fluid component of sediments. Results of this study have shown that interstitial water can represent from 31 to 70 percent of the weight of in situ sediments. Due to the mobility and apparent availability of contaminants dissolved in the interstitial water, the partitioning of contaminants between the solid and liquid phase is of considerable interest.

107. Results of this study showed that sediment anaerobic or reduced conditions favored solubilization and mobilization of Mn, Fe, and As from the sediment solid phase.

108. Easily reducible phase Mn was related to both exchangeable phase and interstitial water Mn. Gotoh and Patrick<sup>3</sup> found that in soils, water soluble plus exchangeable phase Mn increased with decreasing pH and Eh at the expense of easily reducible phase Mn. Gambrell et al.<sup>73</sup> also showed that both pH and Eh regulate levels of soluble and exchangeable Mn in sediments. A decrease in the soluble and exchangeable phases of Mn was accompanied by an increase in reducible phase Mn.<sup>73</sup> In 1931 Piper, cited in Jackson,<sup>49</sup> published a similar relationship for Mn in soils to those given above for reduced sediments and soils.

109. Iron concentrations in the interstitial water of sediments from Mobile Bay, Ashtabula, and Bridgeport were higher than interstitial water Fe concentrations found in shallow marine sediments.<sup>15,24,74</sup> Weiler<sup>24</sup> found that interstitial water in Lake Ontario aerobic sediments contained less than 100 µg/l Fe, increasing to 2000 µg/l in the interstitial water of deeper, anaerobic sediments. Ponnampetuma et al.<sup>75</sup> considered the concentration of water soluble Fe in most submerged soils to be controlled by the effects of Eh and pH on the  $\text{Fe}(\text{OH})_3\text{-Fe}^{2+}$  system, with a more stable interstitial water Fe concentration regulated by the

$\text{Fe}_3(\text{OH})_8\text{-Fe}^{+2}$  equilibrium. Gotoh and Patrick<sup>4</sup> found that water soluble and exchangeable Fe in flooded soils increased as both Eh and pH decreased. This increase in water soluble and exchangeable Fe was at the expense of reducible Fe, thought to consist of ferric hydroxides and oxides. Gambrell et al.<sup>73</sup> found that both pH and Eh strongly affected soluble and exchangeable phase Fe. As the sediment suspensions were oxidized to 250 and 500 mV and/or increased in pH to mildly alkaline levels, water soluble and exchangeable Fe decreased to very low levels.<sup>73</sup>

110. A similar relationship to those observed for Mn was seen with the Ashtabula sediment As results. Interstitial water As was related only to exchangeable phase As. The exchangeable phase As was related to easily reducible phase As. No relationship was seen in any location between interstitial water As and easily reducible phase As. This suggested that a more complex relationship existed among interstitial water, exchangeable phase, and easily reducible phase As than between interstitial water, exchangeable phase, and easily reducible phase Mn. One possibility is that the exchangeable phase served as an intermediary between easily reducible phase As and interstitial water As when As was mobilized from the easily reducible phase by reducing conditions in the sediments.

111. The role of As in oxidation reduction reactions is unclear. Arsenic is subject to oxidation and reduction, having an oxidized state ( $\text{As}^{+5}$ ) and a reduced state ( $\text{As}^{+3}$ ).<sup>76</sup> The reduced state ( $\text{As}^{+3}$ ) is more soluble than the oxidized state ( $\text{As}^{+5}$ ) which is similar to the situation encountered with the oxidized and reduced states of Fe and Mn. The data of Deuel and Swoboda<sup>76</sup> showed that a reduced environment resulted in a greater water-soluble As concentration. These researchers concluded that the solubilization of As at a lower Eh was due to the reduction of Fe and subsequent release of adsorbed As rather than the reduction of As itself. However, intensive reducing conditions were not attained under the experimental conditions of Deuel and Swoboda.<sup>76</sup> No relationship was found between As and Fe released in the easily reducible phase, indicating that reduction of  $\text{As}^{+5}$  to  $\text{As}^{+3}$  may be occurring under the reduced environment of sediments independent of  $\text{Fe}^{+3}$ .

reduction and subsequent release of adsorbed or occluded As.

#### Sulfides

112. The sediments studied were in a reduced state and contained high levels of total sulfides. High concentrations of free sulfides were also found in Bridgeport sediments. These findings led to the assumption that metal concentrations in the sediment interstitial water would be governed by the solubility of their metal sulfide salts. Results of this study, however, indicated that some mechanism involving the sediment interstitial water resulted in Ni, Zn, Cu, and Fe concentrations in the interstitial water greater than would be expected if only the solubility of their simple sulfides were considered. Elderfield and Hepworth<sup>7</sup> calculated sulfide solubility limited Fe, Ni, Zn, and Cu concentrations for sediment interstitial waters with a sulfide activity of  $10^{-10}$  M (0.003  $\mu\text{g}/\ell$ ). At this sulfide activity, Fe, Ni, Zn, and Cu concentrations in sediment interstitial water should be limited to 3.52, 0.18,  $1.04 \times 10^{-6}$ , and  $5.05 \times 10^{-19}$   $\mu\text{g}/\ell$ , respectively.<sup>7</sup> Assuming that  $10^{-10}$  M was a reasonable approximation of sulfide activity in the interstitial water of sediments in this study, then Fe, Ni, Zn, and Cu exceeded their respective sulfide solubilities in the interstitial water of sediments from all areas.

113. Many theories have been forwarded to explain trace metal enrichment in the interstitial waters of sulfide-rich anaerobic sediments. Organic chelation of metals in sediment interstitial water has been implicated as a mechanism for stabilization of soluble metal ions under conditions which should cause them to precipitate.<sup>5-7</sup> However, Blom et al.<sup>77</sup> found no relationship between Zn, Fe, Cu, Ni, and Zn released into sediment interstitial water and total soluble organic C concentrations in the sediment interstitial water. The presence of polysulfide complexes and sulfide salts of greater solubilities has also been implicated as mechanisms for maintaining elevated trace metal concentrations in sediment interstitial waters.<sup>78</sup>

114. Reduction of soluble sulfide concentrations in sediment interstitial waters could also result in elevated trace metal concentrations in sediment interstitial waters. Iron may have been mobilized

into solution from Mobile Bay and Ashtabula sediment solid phases in sufficient quantities to precipitate soluble sulfides<sup>73,79</sup> since no free sulfides were found in sediments from Mobile Bay and Ashtabula. The literature also suggests that Fe may not be capable of precipitating all sulfide generated in anaerobic soils containing high levels of organic matter. Yamane and Sato<sup>80</sup> and Harter and McLean<sup>81</sup> found added Fe ineffective in preventing hydrogen sulfide evolution from muck soils and a soil containing 16 percent organic matter, respectively. Sulfate depletion in the sediments may also have limited sulfide formation. Following the utilization of sulfate in the sediment reservoir, sulfate input from the water to the sediments is limited. Serruya et al.<sup>82</sup> found sulfates diffusing from lake waters into sediments to be rapidly reduced in the surface sediment layers. These results, coupled with results of other workers discussed in the preceding paragraphs, demonstrate that high concentrations of metals can develop in the interstitial water of sediments rich in sulfides, but that the responsible mechanisms are numerous and often unknown.

Trace metal adsorption  
and phase association

115. Many studies<sup>10,11,83</sup> have demonstrated the ability of Fe and Mn oxides to adsorb and coprecipitate trace metals. Lee<sup>21</sup> summarized several papers and concluded that the sorption capacity of hydrous oxides was dependent upon the age of the hydrous oxides. The greatest interaction with heavy metals occurred when heavy metals were present at the time the hydrous oxides were formed. Duchart et al.<sup>15</sup> advanced the argument that reduction of hydrous oxides in sediments may release adsorbed trace metals into solution, increasing their concentrations in the sediment interstitial water. No correlation was seen, however, between Mn or Fe concentration in the interstitial water and the other metals analyzed. Trace metals associated with Mn and Fe oxides, as represented by their concentrations in the easily and moderately reducible phases, did not greatly influence trace metal concentrations in the sediment interstitial water. The results showed that only interstitial water Cu was related to easily reducible phase Cu

concentrations in the sediments. This does not preclude the release of trace metals from hydrous oxides upon reduction, but may be indicative of different control mechanisms, such as differing sulfide solubility and differing stability of metal-organic complexes and chelates for Mn, Fe, and the other trace metals in the interstitial water.

116. The 1 N ammonium acetate extractant (exchangeable phase) was selected to remove cations sorbed on mineral and organic exchange sites. However, no Cu or Cd was extracted with 1 N ammonium acetate from sediments collected at any area. In addition, Zn contamination of the reagent was reduced following extraction of Mobile Bay sediments. The results generally indicated that sorption of Cu, Cd, and Zn was occurring. Ammonium acetate will also extensively dissolve Ca and Mg from  $\text{CaCO}_3$  (calcite) or  $\text{CaCO}_3\text{MgCO}_3$  (dolomite),<sup>49</sup> which may present problems when adapting this selective extraction procedure to calcareous sediments which were not encountered in this study.

117. The hydroxylamine hydrochloride solution primarily extracted the hydrous oxides of Mn, a portion of the hydrous oxides of Fe, and coprecipitated trace elements.<sup>41</sup> Except for Zn in the sediments from Mobile Bay, there was no correlation between Mn and trace metal concentration in the easily reducible phase. Results did indicate, however, that some trace elements were extracted in the easily reducible phase. This indicated that sorption or occlusion of trace metals by a mixed system of hydrous Fe and Mn oxides and hydroxides may be more complex than simple sorption by discrete phases. Krauskopf<sup>11</sup> found that the efficiency of removal of a metal from solution by adsorption was related to both the steady state concentration of metal and the rate of supply. Loganathan and Burau<sup>84</sup> studied the sorption of Zn by  $\delta$ -manganese dioxide and suggested that the sorption process involved the interchange of Zn with Mn(II) in the  $\delta$ -manganese dioxide lattice. Burns<sup>85</sup> proposed that hydrated cations are initially adsorbed onto the surfaces of certain Mn(IV) oxides in the vicinity of vacancies found in the chains or sheets of edge-shared ( $\text{MnO}_6$ ) octahedra. Subsequent fixation of the metals occurs by displacement and replacement of the  $\text{Mn}^{+4}$  by the metals.

118. Results of this study showed that Cu was found in higher

concentrations in the moderately reducible phase rather than the easily reducible phase. Greater concentrations of Cu in the sediments associated with the moderately rather than the easily reducible phase indicated a possible sorption mechanism involving Fe oxides. The literature does not present a clear case for Cu sorption by either Fe or Mn hydrous oxides. Collins<sup>86</sup> attributed the loss of Cu in a mine tailing stream to sorption by Fe hydroxides. Goldberg<sup>10</sup> found the Cu content of deep-sea sediments linearly related to the Mn content and explained the relationship in terms of the adsorption ability of Mn oxides.

119. The adsorption and occlusion of other trace metals by hydrous oxides may be similar to that proposed for Cu by McLaren and Crawford.<sup>44</sup> Their data indicated that Mn has a greater effect than Fe on the amount of Cu occluded. Since Cu associated with the oxide phase is a function of both initial sorption and retention, McLaren and Crawford<sup>44</sup> felt that Mn oxides adsorbed the Cu. Due to their greater abundance, the Fe oxides were implicated as responsible for the occlusion of Cu into the oxides.<sup>44</sup>

120. Nickel and Cu were the only metals extracted from the organic + sulfide phase that correlated with the total organic C content of the sediments. The lack of correlation of the other trace metals with the total organic C content of the sediments was not surprising when the number of factors that can contribute to metal concentration in this phase is considered.

121. Organic partitioning as determined by the acidified hydrogen peroxide ( $H_2O_2$ ) digestion represents a less than complete oxidation of the sediment organic matter.<sup>49</sup> Elemental C and resistant, paraffin-like organic material are not decomposed by the  $H_2O_2$  and to some extent structural (nonhumified) organic matter is not attacked.<sup>49</sup> Alexander and Byers, as cited in Jackson,<sup>49</sup> found as much as 16 percent of the original C content of soils in the residue of the  $H_2O_2$  digest. However, the residual organic material is considered very stable and resistant to decomposition.

122. The large amounts of Mn extracted in the organic + sulfide phase were indicative of another feature of the  $H_2O_2$  digestion. Free

manganese dioxide ( $\text{MnO}_2$ ) remaining after extraction of the easily reducible phase is changed by the procedure to  $\text{Mn}^{++}$  and brought into solution during the digestion along with any  $\text{CaCO}_3$  remaining in the sediment.<sup>49</sup> In the original procedure of Jackson,<sup>49</sup> the soluble  $\text{Mn}^{++}$  is eventually converted to insoluble  $\text{Mn}_3\text{O}_4$  during drying of the digest residue at  $110^\circ\text{C}$  for weight loss determination. The procedure used in this study involved extraction of the wet  $\text{H}_2\text{O}_2$  digest residue rather than drying, maintaining released Mn in the soluble  $\text{Mn}^{++}$  form.

123. Metal-sulfide salts were apparently a source of trace metals extracted in the organic + sulfide phase as evidenced by the numerous positive correlations between metal concentration in the organic + sulfide phase and total sediment sulfide concentration. Fixation of heavy metals by sulfide precipitation has been observed by other workers in reduced environments.<sup>11,55,57</sup> Decomposition of these sulfide salts under oxidizing conditions has also been noted.<sup>87</sup> Arsenic was not associated with the sediment organic matter or sulfide which is in agreement with previous work by Johnson and Hiltholt.<sup>88</sup> Extraction of the sediments resulted in no detectable organic + sulfide phase As; detection limits were  $0.05 \mu\text{g/g}$ .

124. Arsenic distribution in the moderately reducible phase of sediments in this study, ranging between 58 and 96 percent of the total sediment As, agreed with the data of Crecelius et al.<sup>89</sup> These workers found 34 to 66 percent of the total As in sediments from Puget Sound to be extractable with citrate-dithionite or oxalate. Citrate dithionite primarily extracts the hydrous oxides of Fe and Mn.<sup>45,47</sup> Use of the citrate chelating agent with the dithionite aids Fe extraction and removes some coatings of alumina.<sup>45,48</sup>

125. Trace metals associated with the hydrous oxides and hydroxides of Fe would probably have little effect on benthic organisms. Luoma and Jenne<sup>63,64</sup> showed that there was little uptake of Zn or cobalt (Co) by deposit-feeding clams (Macoma balthica) when these metals were coprecipitated with amorphous Fe or Mn oxides. There is little reason to believe that trace metals associated with older Fe oxides in sediments would be more available to benthic clams. Lee<sup>21</sup> reviewed the

literature on the role of Fe oxides in the aquatic environment and found that the crystallinity of hydrous Fe oxide precipitates increased with time. The aggregation of primary particles results in decreasing surface area with time and has been shown to be responsible for the decreased sorption capacity of hydrous oxides with time.<sup>21</sup> Burns<sup>85</sup> found that Co and possibly other hydrated divalent cations become more difficult to leach with aqueous solutions after incorporation into the  $MnO_6$  octahedra.

126. The only trace metal not associated with the hydrous Fe oxides to some extent was Cd. This indicated that although the hydrous oxides may adsorb Cd, it is not strongly adsorbed. Hence, Cd was not retained by the hydrous Fe oxide fraction. Nickel was associated with the moderately reducible phase only in sediments from Ashtabula where the data indicated that Ni extracted in the moderately reducible phase was associated with Mn oxides rather than the more plentiful Fe oxides. It is probable that the Mn extracted in the moderately reducible phase was occluded by Fe oxides since both hydroxylamine hydrochloride and acidified  $H_2O_2$  efficiently extract free Mn oxides. This further supports the contention of McLaren and Crawford<sup>44</sup> that Fe oxides are responsible for the occlusion of trace metals adsorbed by hydrous Mn oxides.

127. The results of this investigation showed that Cu and Cd in sediments from Mobile Bay, Mn in sediments from Bridgeport, and Ni in sediments from all areas were associated primarily with the residual phase. The association of Ni with the residual phase agreed with the findings of Chester and Messiha-Hanna,<sup>40</sup> who found the majority of Ni near the continents in the residual fraction. The residual phase trace metals are those associated with mineral lattices. Metals in this phase are thought to be stable and biologically inactive.<sup>34,59</sup> Even the internal stomach acidity of benthic organisms will not mobilize metals in the residual phase.<sup>59</sup> The short- and long-term environmental impacts of the metals found in the residual phase of the sediments are therefore expected to be negligible.

### Sediment Nutrient Distribution

128. The results showed that ammonium-N and orthophosphate reached high concentrations in the sediment interstitial waters, with the exception of orthophosphate in sediments from Bridgeport. These results agreed with the findings of other workers,<sup>16,19,22</sup> who have reported high concentrations of ammonium-N and orthophosphate in sediment interstitial waters.

129. A portion of the ammonium-N concentration in the interstitial water may have been a storage artifact, even though the interstitial water was extracted within a week of sample acquisition. Ho and Lane<sup>22</sup> suggested that storage of sediments in airtight containers at 4°C can release additional ammonium-N into the interstitial water within a week after sampling due to decomposition of organic constituents.

130. The reduced conditions in the sediments were responsible for the high concentrations of interstitial water orthophosphate. Orthophosphate concentrations increase in the water-soluble phase of flooded soils and sediments when reducing conditions are present.<sup>22,74,90-92</sup> Patrick<sup>18</sup> showed that extractable Fe and orthophosphate concentrations increase with a decrease in Eh below +200 mV. Gambrell et al.<sup>73</sup> and Patrick and Mahapatra<sup>17</sup> attributed orthophosphate concentration increases in pore waters of reduced sediments and soils to reduction of ferric phosphate to the more soluble ferrous forms, release of occluded phosphates, and hydrolyses of pyrophosphate.

131. The results showed that the majority of sediment N was present in an organic complex expected to have a limited availability based on earlier results by Keeney et al.<sup>93</sup> Organic N is transformed by microorganisms to ammonium-N, the first inorganic product of N mineralization.<sup>17</sup> Ammonium-N tends to accumulate in anoxic sediments.<sup>19,23,93</sup>

132. Exchangeable phase ammonium-N concentration in the sediments was directly related to the >50 µm particle-size fraction. This did not agree with the data of Maye,<sup>94</sup> who found the percentage of clay (<2 µm) to be the factor controlling exchangeable ammonium-N concentration in

Georgia marsh soils. The results showed that exchangeable phase ammonium-N concentrations were related to interstitial water ammonium-N concentrations within each of the sampling areas. No overall relationship was seen between interstitial water and exchangeable phase ammonium-N concentrations, indicating a very area-specific relationship.

#### Metals and Nutrients in the Standard Elutriate

##### Metal and nutrient mobility

133. The results indicated that metal concentrations in the sediment phases thought to be the most mobile were related to their respective concentrations in the standard elutriate. When considering both site specific and nonsite specific (considering all data) correlations, 27 significant correlation coefficients were found between metal and nutrient concentrations in the standard elutriate and the various sediment phases. Of these correlations, 29.7 percent were between concentrations in the standard elutriate and interstitial water, 22.2 percent between concentrations in the standard elutriate and the exchangeable phase, 25.9 percent between concentrations in the standard elutriate and the easily reducible phase, 14.8 percent between concentrations in the standard elutriate and organic + sulfide phase, and the remaining 7.4 percent between standard elutriate ammonium-N concentration and TKN concentration. Thus 77.8 percent of the correlations between standard elutriate concentrations and sediment phases analyzed in this study occurred with either the interstitial water, exchangeable phase, or easily reducible phase, which indicated that contaminants associated with the interstitial water, exchangeable phase, and easily reducible phase showed the most mobility into the standard elutriate. The organic + sulfide phase was related in a few instances to Zn and Ni concentrations in the standard elutriate, but the digestion used to obtain the organic + sulfide phase is a harsh procedure. It is doubtful that significant amounts of metals associated with the organic + sulfide phase would be available to benthic organisms following aquatic disposal of sediments.

134. No relationship existed between trace metal concentrations in the standard elutriate and total sediment metal concentrations for Fe, Mn, Cu, Ni, As, Cd, and Zn. The TKN concentrations in the sediments were related to ammonium-N concentrations in the standard elutriate. Ammonium-N concentrations measured in the interstitial water and the exchangeable phase were also measured in the TKN analysis.<sup>68</sup> The interstitial water and exchangeable phase contribution to TKN ammonium-N concentrations ranged between 8.5 and 12.7 percent of total TKN. This contributed to the existence of a relation between ammonium-N concentration in the standard elutriate and TKN concentration.

135. Trace metal concentrations in the moderately reducible and residual phases were not related to trace metal concentrations in the standard elutriate. No relationship was found despite the fact that the majority of sediment Fe, As, and Ni were extracted in the residual, moderately reducible, and residual phases, respectively. The mobility of the more easily extracted phases, coupled with the immobility of metals in the moderately reducible and residual phases, demonstrated that the physicochemical form of bound metals was a greater factor than total metal concentration in determining the mobility of metals into the standard elutriate.

136. The relationship between metal physicochemical form and mobility into the standard elutriate was well illustrated by the Mn results. Interstitial water Mn, which would be expected to be immediately mobile, showed the highest degree of correlation with Mn concentrations in the standard elutriate. Manganese in the exchangeable and easily reducible phases, initially not in solution in the sediments, showed lesser degrees of correlation with Mn concentrations in the standard elutriate. This indicated a lower degree of mobility for exchangeable phase and easily reducible phase Mn than for interstitial water Mn, even though actual Mn concentrations increased in the order of easily reducible phase > exchangeable phase > interstitial water.

137. Metals associated with the organic + sulfide phase would be expected to be relatively immobile due to the harshness of the acidified  $H_2O_2$  digest used to obtain this phase. However, the results

indicated that Zn, Cu, and Ni in this phase were somewhat mobile. Metal mobilization from the organic + sulfide phase into the standard elutriate could be caused by metal sulfide oxidation and release of sulfide-bound metals into solution during the elutriate test procedure.

138. Zinc, Cu, and Ni concentrations in the organic + sulfide phase, in addition to being related to their concentrations in the standard elutriate, were related to total sediment sulfide concentration. This indicated that Zn, Cu, and Ni sulfides were being extracted in the organic + sulfide phase. Sulfide oxidation can proceed rapidly when oxygen ( $O_2$ ) is present,<sup>95</sup> but metals released into solution would be expected to be rapidly adsorbed by sediment solid phases.<sup>89</sup> Significant amounts of Zn were not adsorbed by the sediment as evidenced by the high Zn concentrations found in the standard elutriate. These high Zn concentrations were not found by Lee et al.<sup>61</sup> in the standard elutriate of sediments from the same areas. However, the elutriate test as used by Lee et al.<sup>61</sup> was a modification of the standard elutriate test that included air agitation of the sediment-water mixture. This ensured the presence of  $O_2$  throughout the half-hour agitation period, and resulted in greater precipitation of Fe oxides and hydroxides than would have been in the case if  $O_2$  became depleted during the elutriate test procedure.<sup>20</sup> This would hold true for elutriate tests at the same pH, because the precipitation of Fe oxides and hydroxides becomes much slower as the pH decreases.<sup>20</sup> The increased rate of Fe precipitation during an aerobic elutriate test would result in increased adsorption of trace metals<sup>10-12</sup> from solution during the course of the elutriate test.

139. Zinc concentrations in the standard elutriate may have also been influenced by the formation of Zn organic complexes. Gambrell et al.<sup>73</sup> found that at a pH of 7.5 the majority of water soluble Zn in anaerobic sediments was strongly complexed with soluble ligands. Cheam et al.<sup>96</sup> has shown that complexing material with a reacting strength similar to fulvic acid is released during the elutriate test procedure. Blom et al.<sup>77</sup> have also found metal complexing agents in water following sediment resuspension. However, Price<sup>97</sup> has reported that when organic

complexes migrate from an environment that is reducing in character into one that is oxidizing, the metals in the complexes will tend to precipitate, the extent of precipitation depending upon the stability of their respective complexes. As previously discussed, there is evidence that  $O_2$  depletion occurred during the elutriate test procedure. Lack of complete aerobic conditions during the elutriate test, coupled with the existence of water-soluble complexed Zn in sediments,<sup>73</sup> may have resulted in migration of complexed Zn from the interstitial water into the standard elutriate of sediments from Ashtabula and Bridgeport, thereby contributing to the high Zn concentrations found in the standard elutriate of sediments from those areas.

140. Sediments from each sampling area produced a standard elutriate with high concentrations of ammonium-N. Ammonium-N concentrations in the standard elutriate were related to ammonium-N concentrations in the exchangeable phase. These results indicated that the exchangeable phase had a greater effect than the interstitial water upon ammonium-N concentrations in the standard elutriate. The lowest ammonium-N concentrations found in the standard elutriate were in sediments from Mobile Bay. Lee et al.<sup>61</sup> studied ammonium-N release from sediments into the standard elutriate and also found the lowest release of ammonium-N from sediments in Mobile Bay.

141. Iron concentrations in the standard elutriate were low due to the precipitation of Fe oxides and hydroxides when reduced sediments were mixed with oxygenated disposal water. Iron oxides and hydroxides have a great effect upon heavy metal release in the elutriate test, since Fe oxides and hydroxides have been shown to be scavengers of trace metals and orthophosphate.<sup>9-12</sup> Results of this study indicated that Fe oxides and hydroxides formed by the oxidation of  $Fe^{+2}$  to  $Fe^{+3}$  from the sediments were related to heavy metal and orthophosphate concentrations in the standard elutriate. Orthophosphate concentrations were inversely related to Fe concentrations in the interstitial water and exchangeable phase. The most general release of trace metals in the elutriate test was seen using sediments from Bridgeport and disposal water from Eatons Neck disposal site in Long Island Sound. Interstitial water and

exchangeable phase Fe concentrations were low in sediments from Bridgeport. Trace metal and orthophosphate release can therefore be expected to be higher from sediments low in interstitial water and exchangeable phase concentration than from similar sediments higher in interstitial water and exchangeable phase Fe concentration.

#### Evaluation using EPA criteria

142. Any comparison between water-quality standards and elutriate concentrations, although useful in evaluating the water quality of the standard elutriate, must consider that contaminant concentrations in the standard elutriate do not reflect the immediate dilution that occurs at dredging and disposal sites. This dilution results in an immediate reduction in metal and nutrient concentrations observed in the standard elutriate.

143. Evaluation of elutriate test results using the EPA water-quality standards showed that average Zn and Mn concentrations in the standard elutriate exceeded the October 1973 EPA proposed criteria for water quality cited by Lee et al.<sup>61</sup> In the proposed 1975 EPA water-quality criteria,<sup>98</sup> Mn standards remained unchanged but the Zn criterion was stated as 0.01 of a 96-hr LC50 (the concentration that is lethal to 50 percent of test organisms in a 96-hr period); no comparison can therefore be made for Zn using concentration alone.

144. No direct comparison can be made between ammonium-N concentrations in the standard elutriate and water-quality standards because standards are expressed in terms of un-ionized ammonia. The pH and temperature measurements of the standard elutriate needed to convert ammonium-N concentrations to un-ionized ammonia concentrations were not conducted during this study. However, assuming room temperature (20°C) and a pH near neutrality, an estimate of the concentrations of un-ionized ammonia in the standard elutriates can be made. Using the method of Emerson et al.,<sup>99</sup> standard elutriates from Mobile Bay, Ash-tabula, and Bridgeport sediments contained average un-ionized ammonia concentrations of 2, 163, and 223 µg/l, respectively. Even though un-ionized ammonia concentrations in the standard elutriates were orders of magnitude lower than ammonium-N concentrations, the standard

elutriate of sediments from Ashtabula and Bridgeport exceeded the 1975 proposed EPA water-quality criteria of 20  $\mu\text{g}/\text{l}$ .

145. Water-quality standards for As are 50  $\mu\text{g}/\text{l}$  for domestic water supplies and 100  $\mu\text{g}/\text{l}$  for irrigation water; no standards are set for aquatic life.<sup>98</sup> Arsenic concentrations commonly found in uncontaminated waters range from 1 to 10  $\mu\text{g}/\text{l}$ .<sup>100</sup> This range of As concentrations encompassed the average As concentrations found in the standard elutriate.

#### Biological significance of releases

146. In areas such as Bridgeport where a higher concentration of heavy metals and nutrients in the standard elutriate was observed, the question of the biological significance of this release arises. Shuba et al.<sup>101</sup> conducted sampling operations in Bridgeport concurrently with this project and ran static algal bioassays on various elutriate test/disposal water mixtures. Results of growth experiments using Dunaliella tertiolecta showed that the algae grew better in all combinations of elutriate and disposal site water than they did on 100 percent disposal site water. Growth was highest in the combination of 25 percent elutriate and 75 percent disposal site water, and decreased as the elutriate contribution was increased to 100 percent. One explanation for these results was that the elutriate from all sampling sites contained one or more growth stimulating agents at lower concentrations of elutriate that became inhibitory as their concentration increased. Another explanation for the above-mentioned results is that a compound(s) other than the stimulant was present that had no effect at low concentrations, but was inhibitory at high concentrations. Algal bioassays conducted on the standard elutriate of sediments from Ashtabula harbor showed no suppression of algal growth when compared with algal growth in dredging site water.<sup>101</sup>

### Sediment Effect on Water Quality

#### Sediment/water interactions

147. Difficulty was encountered in assessing the effect of

sediments on water quality since man's contaminant input into the water effectively masks most impacts of sediments on water quality. Some sediment impact on water quality was, however, evident. The most obvious water-quality degradation found was the depletion of DO in the bottom waters of Mobile Bay and Ashtabula. This indicated that the sediments were exerting a high oxygen demand and consuming more oxygen than could be supplied by the overlying water.

148. The results showed high ammonium-N concentrations in the waters of Ashtabula and Bridgeport and high orthophosphate concentrations in the water of Bridgeport. The results also showed that DO concentration was greater than 2.0 mg/l at all but one sampling site. Other workers<sup>29-32</sup> have shown that ammonium-N and orthophosphate transfer from sediments into the overlying water is minimal when DO concentrations in water are greater than 2 mg/l. The results showed that no relationship existed between ammonium-N or orthophosphate concentrations in the bottom waters and the interstitial water of the surface sediment. If any ammonium-N was being released into the water, conversion to nitrate could have been occurring, thereby reducing the ammonium-N concentrations in the water. Ammonium-N in an oxygenated water column may be readily oxidized to nitrite and then to nitrate.<sup>102</sup>

149. Copper concentration in the bottom waters of Bridgeport were related to Cu concentrations in the organic + sulfide phase of surface sediments from Bridgeport. These results indicated that the organic + sulfide phase of the sediment was probably acting as a sink for Cu. It was unlikely that Cu was diffusing from the interstitial water of the sediment into the bottom waters since a concentration gradient from the interstitial water to the bottom waters was absent. The distribution of Cu in the water could be explained by point source Cu contamination near sites 3 and 5 in Bridgeport harbor. Sites 3 and 5 were on different sides of the harbor: site 3 near the outlet of a small drainage canal and site 5 at the mouth of a small river. Sites 1, 2, and 4 were downstream from sites 3 and 5, which would result in dilution of any contaminant with a source upstream of site 3 or 5.

150. Leaching from the sediment solid phase into the overlying

water could contribute to Cu concentrations in Bridgeport bottom waters; sediment solid phase Cu concentrations were related to Cu concentrations in both the standard elutriate and the interstitial water. Results of Bridgeport elutriate tests indicated, however, that sediment solid phase Cu contributions to the overlying water during resuspension would be relatively minor, for only low Cu concentrations were found in the standard elutriates.

#### Evaluation using EPA criteria

151. Of the metals determined in the bottom waters, Cu in Bridgeport was the only metal exceeding the 1973 EPA proposed water-quality criteria. From the data available, it is impossible to evaluate water quality at the sampling sites in relation to the 1975 proposed EPA water-quality criteria.<sup>98</sup> Concentration levels in the 1975 proposed EPA water-quality criteria are usually some fraction of a 96-hr LC50, and such bioassay data are not available for the waters sampled in the study.

152. The 1975 EPA proposed water-quality criterion sets an upper limit of 20 µg/l for un-ionized ammonia. To facilitate comparison, the method of Emerson et al.<sup>99</sup> was used to convert ammonium-N concentrations into un-ionized ammonia concentrations in the bottom waters of the sampling areas. Results of this conversion showed that average concentrations of un-ionized ammonia in Ashtabula and Bridgeport bottom waters were 7.74 and 2.94 µg/l, respectively. The highest concentration of un-ionized ammonia at any site was 18.19 µg/l in the waters of site 4, Bridgeport. Ammonium-N concentrations in Mobile Bay bottom waters were below the detection limits of 1 µg/l. The 1975 EPA proposed water-quality criterion for un-ionized ammonia in water (20 µg/l) was, therefore, not exceeded in any area or any sampling site within an area.

#### Impact of dredging and disposal operations

153. Chemical partitioning of the sediments provided insight into the potential effect of the sediments on water quality during dredging operations. The high concentrations of Fe(II) in the interstitial water

and exchangeable phase have a great potential to affect water quality during dredging and aquatic disposal of sediments. The scavenging effect of Fe oxides would serve to decrease the concentration of trace metals and phosphate released into the water column.<sup>10,11,60</sup> This phenomenon has been observed during actual dredging operations<sup>60</sup> and was observed in this study, specifically in the Bridgeport elutriate tests where the highest general release of metals and orthophosphate occurred from sediments low in interstitial water and exchangeable phase Fe.

154. Manganese and ammonium-N were highly concentrated in the sediment interstitial water. The interstitial water would be expected to be immediately mobile during dredging operations when water is mixed with the sediments. Manganese and ammonium-N are not scavenged by Fe oxide precipitation and are water soluble. Release of Mn and ammonium-N at the dredging and open-water disposal sites could therefore be expected.

#### Comments on the Selective Extraction Procedure

155. The results of this study indicated that the selective extraction procedure had good mass balance for most metals, though some difficulties were encountered with Fe and As. The distilled water wash following the extraction of the moderately reducible phase was found to extract additional Fe from the sediment; this Fe loss was remedied by dispensing with the wash. Arsenic presented problems due to low concentration in the extracts and matrix problems in the extractants. Reproducibility of the extraction procedures was good, although some large coefficients of variation were seen due to the small absolute numbers involved.

156. Analysis of the sources of variation in Mobile Bay data, especially Fe, Mn, and Zn data that were available early in the study, indicated that the main source of statistical variation was between sites within an area. The variation between replicate extractions for each depth segment in a core and the variation between extractions in

cores taken from the same site were usually much smaller than the variation between sites. The sampling program was therefore expanded to include five sites in each location and the number of cores in a site reduced to two. Replication of extraction in each depth segment of each core within a site was also discontinued. Replicate extractions were run upon some samples to ensure that extraction techniques continued to have a low degree of variation.

157. Zinc presented the most problems in the sediment fractionation procedure due to Zn contamination of the sodium dithionite used in extraction of the moderately reducible phase, resulting in a Zn carry-over into the residual phase. This necessitated the determination of Zn concentration in the residual phase by the difference between the sum of the remaining fractions and the analytical total.

158. Most "purified" grades of sodium dithionite are excessively contaminated with Zn; however, preliminary work showed that the Zn could be extracted with 3 percent ammonium pyrrolidine dithiocarbonate (APCD) in methyl isobutyl keton (MIBK)\* without a decrease in the reducing activity of the dithionite. Several hundred grams of sodium-dithionite were purified to some extent in this manner, but Zn levels remained rather high.

159. Reagent grade ammonium acetate also contained excessive amounts of some trace metals, which necessitated preparation of 1N ammonium acetate from acetic acid and ammonium hydroxide<sup>49</sup> to lower contaminant levels.

160. The effects of temperature changes during sample collection and preparation are very important and should be considered.<sup>13,14,103-106</sup> If at all possible, the operational procedure should be conducted at in situ temperatures. If an in situ temperature cannot be maintained, storage and manipulation are best done at about 4°C. Kalil and Goldhaber<sup>107</sup> have proposed an inexpensive, portable sediment squeezer for extracting interstitial water at in situ temperatures under a N

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\* This solid-liquid extraction must be free of water and the extracted dithionite should be well rinsed with APCD-free MIBK.

atmosphere. This could be used in place of centrifugation to obtain sediment interstitial water.

161. The organic + sulfide phase of the selective extraction procedure was extracted prior to the moderately reducible phase because an unknown portion of the organic fraction was dissolved by the citrate-dithionite. Complete oxidation of the sediment by the hydrogen peroxide treatment did not appear to impair extraction of the moderately reducible phase; consequently, it was performed after the hydrogen peroxide digestion.

## PART VI: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

162. The principal findings of this study of metal and nutrient distribution in freshwater and marine sediments and the relationship these distributions have with metal concentrations in the standard elutriate are as follows:

- a. No relationship existed between trace metal concentration in the standard elutriate and total metal concentration in the sediment. This held true even though some sediments were apparently highly contaminated with some trace metals. This clearly suggests that sediments can be a stable sink or repository for some contaminants.
- b. The elutriate test represented those sediment phases thought, and documented in many cases, to be most mobile and biologically available in the aquatic environment. Mobility of trace metals and nutrients into the standard elutriate was significantly related in the majority of cases to respective concentrations in the interstitial water, exchangeable phase, or easily reducible phase.
- c. Trace metals extracted in the moderately reducible phase and bound in mineral lattices (residual phase) were not related to trace metal concentrations in the standard elutriate. This occurred despite the fact that the majority of sediment As and Ni (and in some cases Fe and Cu) were extracted in the moderately reducible and residual phases, respectively.
- d. The concentration of reduced Fe in the interstitial water and the exchangeable phase had a significant inhibitory effect upon the amount of orthophosphate and trace metals released during the elutriate test and subsequently into the water column during aquatic disposal.
- e. The concentrations of Fe, Cu, Zn, and Ni in the interstitial water were not controlled by the solubility of their simple sulfide salts.
- f. The selective extraction procedure can determine the operationally defined phases in a sediment with good mass balance and precision. Metals extracted in any particular phase are not discrete forms of the metal but are operationally defined by the method of extraction.
- g. Total Kjeldahl nitrogen was correlated with ammonium-N concentration in the standard elutriate. Ammonium-N concentrations in the mobile interstitial water and

exchangeable phase were also determined in the TKN procedure and constituted a significant fraction of the TKN.

- h. Of the constituents determined, only Zn, Mn, and  $\text{NH}_4^+$ -N concentrations in the standard elutriate exceeded the EPA water-quality standards. However, the concentration of any constituent in the standard elutriate does not reflect the dilution that occurs at the dredging and disposal site.
- i. Sediment Fe was found primarily in the residual and moderately reducible phases in all areas. Interstitial water and exchangeable phase Fe, which have little if any deleterious effect on water quality during disposal of sediment, were present in high concentrations in sediments from Mobile Bay and Ashtabula.
- j. Sediment Mn was found mainly in the organic + sulfide and residual phases. Manganese concentrations in the interstitial water, exchangeable phase, and easily reducible phase were related to Mn concentration in the standard elutriate.
- k. Sediment Cu was found mainly in the residual and organic + sulfide phases, with the Cu concentration in the organic + sulfide phase increasing as the total Cu concentration of the sediment increased.
- l. Sediment Zn was found mainly in the organic + sulfide phase in all areas. Zinc concentrations in the standard elutriate were related to Zn concentrations in the easily reducible and organic + sulfide phases.
- m. Sediment Ni was primarily associated with the residual phase in all areas. Nickel in the organic + sulfide phase was of secondary importance and was related to the total organic carbon content of the sediments.
- n. Cadmium was concentrated mainly in the residual phase in sediments from Mobile Bay. In sediments from Ashtabula and Bridgeport, the majority of Cd was found in the organic + sulfide phase. No significant mobility of Cd into the standard elutriate was observed for sediments from any area.
- o. Arsenic was associated with the moderately reducible phase in sediments from all areas. Arsenic concentrations in the standard elutriate were related to As concentrations in the exchangeable phase in sediment from Ashtabula.

#### Recommendations

163. When investigating the effect of dredging operations upon

water quality of dredging and disposal site water, sediment chemical extractants should be selected that remove mobile sediment phases. Elements bound in immobile phases are unlikely to be chemically or biologically active. In addition to the extractants used in this study, an additional extractant is needed to evaluate the concentration of complexed cations in sediments.

164. A wide range of chemical extractants and sediments should be used when evaluating the mobility of sediment constituents into the standard elutriate. A study of this type should thoroughly investigate ammonium-N release in the standard elutriate for ammonium-N showed area-dependent release patterns.

165. The elutriate test and other extractants that remove the more mobile sediment phases should be used to evaluate long-term mass release of contaminants from sediments following aquatic disposal. The feasibility of using the elutriate test to predict interstitial water and other mobile phase concentrations in sediments following aquatic disposal should be evaluated.

166. The elutriate test represents the more mobile contaminants in sediments and should continue to be used in evaluating open-water disposal of dredged material.

167. The DO concentration in the site water used in the elutriate test can affect the results. The oxygen content of the elutriate water during the test should be standardized to reflect the oxygenated conditions that usually prevail at dredging and open-water disposal sites.

168. Criteria studies should be initiated that will provide a basis for interpreting the chemical and biological effects on contaminants released in the elutriate test.

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SELECTIVE ANALYTICAL PARTITIONING OF SEDIMENTS TO EVALUATE POTE--ETC(U)  
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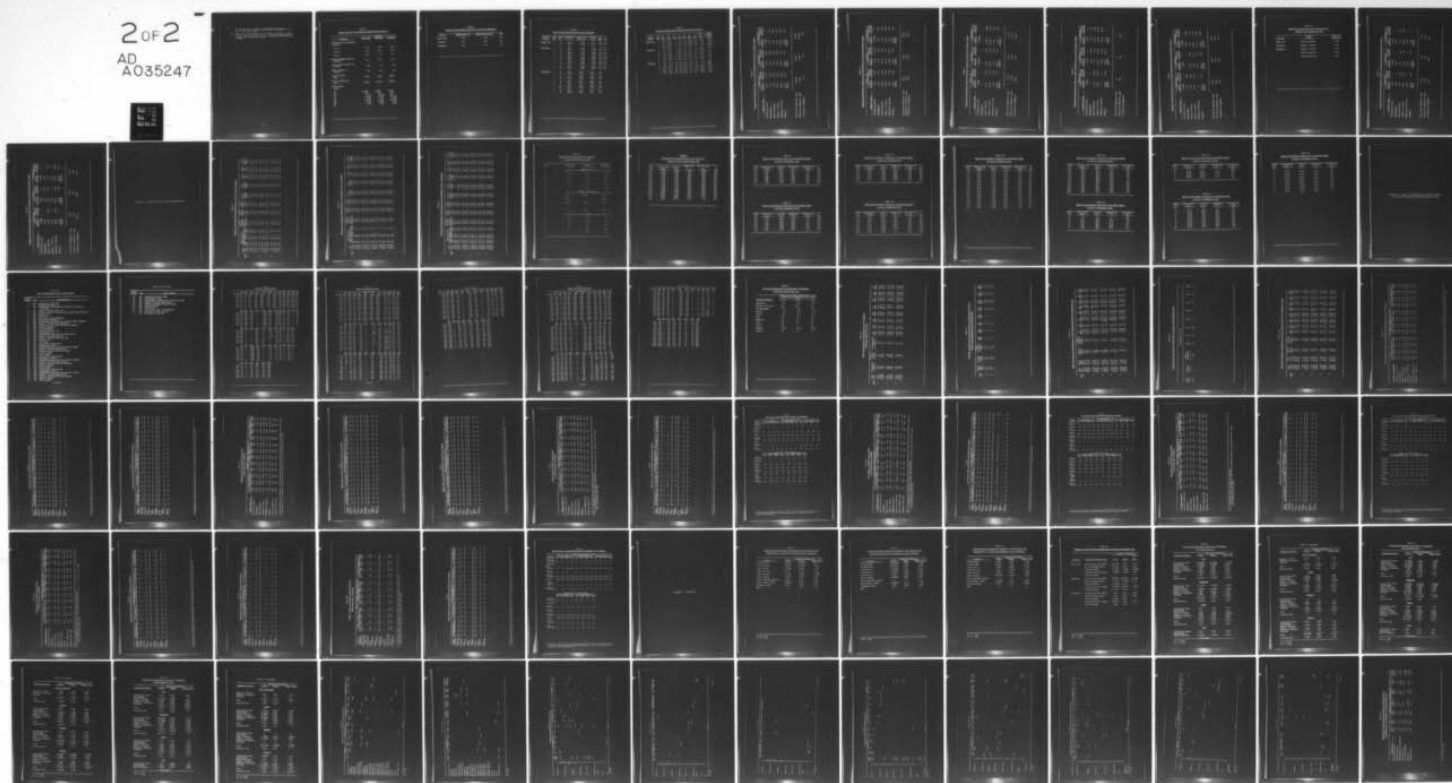
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Table 1  
Average Physical and Chemical Sediment Characteristics

Parameter	Location		
	Mobile Bay	Ashtabula	Bridgeport
Particle-size distribution, percent:			
<2 $\mu\text{m}$	52.7	36.0	38.3
2-50 $\mu\text{m}$	32.5	62.7	58.2
>50 $\mu\text{m}$	14.8	1.3	3.5
Cation exchange capacity, meq/100 g	46.3	16.9	23.9
Total organic carbon (C), percent	2.03	2.42	2.69
Total inorganic C, percent	0.07	0.56	2.19
Total sulfides, $\mu\text{g/g}$	903.0	240.0	2,680.0
Total nitrogen (N), $\mu\text{g/g}$	1,900.0	1,390.0	2,680.0
Total metals, $\mu\text{g/g}$ :			
Fe	42,900	42,400	43,600
Mn	746	642	531
Cu	37.48	40.87	1,117
N	156.00	213.00	203.00
Cd	3.62	4.14	17.60
Zn	234.00	444.00	1067.00
As	4.08	6.50	6.90
Hg	0.52	0.61	1.12

Table 2  
Average Physicochemical Properties of Surface Sediments

<u>Area</u>	<u>Temperature, °C</u>	<u>Redox Potential, mV</u>	<u>pH</u>
Mobile Bay	17.0	-186	6.9
Ashtabula	21.9	-103	6.5
Bridgeport	14.9	-144	6.8

Table 3  
Water Column Characteristics During Sampling

<u>Sampling Area</u>	<u>Site No.</u>	<u>Depth m</u>	<u>Temperature °C</u>	<u>Conductivity mmho/cm</u>	<u>Salinity ppt</u>	<u>DO mg/l</u>	<u>pH</u>
Mobile Bay	1	0	13.7	1.16	1.0	10.8	5.9
		8	15.0	15.42	11.8	3.6	6.1
Ashtabula	1	0	27.4	1.29	0.77	7.5	7.6
		3	25.4	1.73	1.07	1.4	7.1
	2	0	26.0	1.52	0.89	6.4	6.8
		4	25.8	1.66	1.03	2.1	7.1
	3	0	26.8	1.57	0.95	6.7	8.0
		5	23.5	0.49	0.32	4.8	7.8
	4	0	25.5	1.01	0.62	6.5	7.9
		8	23.3	0.39	0.25	6.1	7.8
	5	0	23.8	0.36	0.24	8.7	7.6
		8	23.1	0.32	0.22	7.3	8.1
Bridgeport	1	0	14.5	26.6	26.5	8.2	
		12	14.9	34.0	27.1	7.1	
	2	0	14.7	32.8	26.4	8.0	
		6	14.5	33.0	26.6	7.0	
	3	0	14.4	32.7	26.5	8.0	
		4	14.1	32.6	26.5	7.2	
	4	0	17.0	33.7	26.9	8.5	
		10	15.5	34.4	27.2	7.8	
	5	0	16.0	34.5	27.1	8.8	
		8	15.8	34.6	27.1	7.6	

Table 4  
Nutrient and Heavy Metal Concentrations of Bottom Waters

Sampling Area	Site No.	Fe $\mu\text{g/l}$	Mn $\mu\text{g/l}$	Cu $\mu\text{g/l}$	Zn $\mu\text{g/l}$	Ni $\mu\text{g/l}$	Cd $\mu\text{g/l}$	As $\mu\text{g/l}$	$\text{NH}_4^+\text{-N}$ $\mu\text{g/l}$	Ortho-phosphate $\mu\text{g/l}$
Mobile Bay	1	25.0	90.0	5	4.2	2.0	<0.05	<1.0	<1.0	25.08
	2	25.0	40.0	4	11.0	2.4	<0.05	<1.0	<1.0	19.36
	3	35.0	130.0	2	8.0	2.0	<0.05	<1.0	<1.0	28.60
Ashtabula	1	2.0	41.0	5	18.0	6.0	1.1	1.2	258.0	2.5
	2	1.3	8.0	3	20.0	1.0	0.2	1.0	65.0	8.7
	3	3.0	114.0	2	20.0	5.0	0.5	1.2	247.0	<2.0
	4	6.0	27.0	1	18.0	4.0	0.3	1.2	93.0	<2.0
	5	8.0	49.0	3	19.0	7.0	1.0	0.8	56.0	2.0
Bridgeport	1	34.0	22.6	36	6.0	15.0	2.6	1.0	84.7	260.0
	2	6.0	47.2	19	8.0	11.0	3.0	1.0	1.4	69.4
	3	55.0	36.9	70	8.0	14.0	1.2	<1.0	136.9	332.0
	4	230.0	27.7	80	11.0	48.0	4.0	<1.0	213.2	174.0
	5	35.0	39.0	115	13.0	44.0	1.0	<1.0	157.9	99.0

Table 5

## Average Fe Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.19	0.14	0.13	0.05	0.0007	--
Exchangeable	1.42	0.62	1.30	0.38	0.18	0.75
Easily reducible	3.48	1.00	0.73	0.81	2.07	0.97
Organic + sulfide	15.52	3.51	2.34	0.79	8.84	1.65
Moderately reducible	70.46	2.08	34.59	4.20	35.01	3.00
Residual	8.57	0.33	60.91	4.32	53.90	3.24
	100.00		100.00		100.00	
<hr/>						
Total Fe by summation, $\mu\text{g/g}$	30,100		40,500		42,900	
Total Fe by digestion, $\mu\text{g/g}$	42,900		42,200		43,600	
% recovery by summation	70.2		95.9		98.4	

Table 6  
Average Mn Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	1.30	0.67	0.50	0.36	0.0005	--
Exchangeable	8.61	3.51	4.31	2.16	0.25	0.43
Easily reducible	19.18	8.29	12.15	3.05	2.30	1.56
Organic + sulfide	46.60	6.80	40.73	9.62	30.81	6.04
Moderately reducible	8.15	1.50	10.98	11.15	3.75	0.85
Residual	16.11	4.89	31.77	6.49	62.89	6.85
	<u>100.00</u>		<u>100.00</u>		<u>100.00</u>	
<hr/>						
Total Mn by summation, µg/g	723.7		670.4		591.2	
Total Mn by digestion, µg/g	746.5		642.2		531.5	
% recovery by summation	96.9		104.4		111.2	

Table 7

## Average Cu Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.00004	--	0.000006	--	0.000006	--
Exchangeable	--	--	--	--	--	--
Easily reducible	0.74	1.60	0.04	0.06	0.008	0.006
Organic + sulfide	34.26	3.37	59.91	8.24	92.00	1.81
Moderately reducible	5.81	3.82	4.43	3.66	0.40	0.33
Residual	59.19	4.73	35.62	6.35	7.60	1.86
	100.00		100.00		100.00	
Total Cu by summation, $\mu\text{g/g}$	41.55		36.30		13.21	
Total Cu by digestion, $\mu\text{g/g}$	37.48		40.87		11.17	
% recovery by summation	110.8		88.8		118.2	

Table 8

## Average Zn Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.0001	--	0.52	--	0.10	--
Exchangeable	--	--	0.35	0.60	0.33	0.31
Easily reducible	2.22	0.88	5.33	2.59	13.73	5.60
Organic + sulfide	54.75	11.84	43.67	20.61	56.48	15.50
Moderately reducible	--	--	29.19	13.41	22.11	17.84
Residual	43.03	12.17	20.94	21.48	7.24	--
	<u>100.00</u>		<u>100.00</u>		<u>100.00</u>	
<hr/>						
Total Zn by summation, $\mu\text{g/g}$	--		--		--	
Total Zn by digestion, $\mu\text{g/g}$	234		444		976	
% recovery by summation	--		--		--	

Table 9

## Average Ni Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.0007	--	0.0004	--	0.00006	--
Exchangeable	0.49	0.66	--	--	0.024	0.024
Easily reducible	1.67	1.10	0.67	0.24	1.64	1.02
Organic + sulfide	6.40	1.09	9.61	3.47	25.35	8.56
Moderately reducible	--	--	23.27	2.17	0.43	0.49
Residual	91.44	1.79	66.45	3.92	72.56	9.56
	100.00		100.00		100.00	
<hr/>						
Total Ni by summation, $\mu\text{g/g}$	127.2		184.0		178.8	
Total Ni by digestion, $\mu\text{g/g}$	156.2		212.7		203.5	
% recovery by summation	81.4		86.5		87.9	

Table 10  
Degree of Correlation of Ni Concentration in  
Sediment and Standard Elutriate

<u>Location</u>	<u>Sediment Phase</u>	<u>Degree of Correlation</u>
Mobile Bay	Easily reducible	0.506
Ashtabula	Organic + sulfide	0.436
Bridgeport	Organic + sulfide	0.553
	Easily reducible	0.410
	Interstitial water	0.394

Table 11  
Average Cd Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.00	--	0.0002	--	0.001	--
Exchangeable	0.00	--	0.00	--	0.00	--
Easily reducible	0.60	0.26	3.18	2.41	4.32	2.31
Organic + sulfide	18.40	4.85	78.02	7.66	95.68	2.31
Moderately reducible	0.00	--	0.00	--	0.00	--
Residual	81.00	5.02	18.80	7.90	0.00	--
	<u>100.00</u>		<u>100.00</u>		<u>100.00</u>	
<hr/>						
Total Cd by summation, µg/g	3.48		4.81		15.09	
Total Cd by digestion, µg/g	3.60		4.13		17.60	
% recovery by summation	96.7		116.5		85.7	

Table 12

## Average As Distribution Among the Various Chemically Extracted Sediment Phases

Chemical Phase	Mobile Bay		Ashtabula		Bridgeport	
	% by Summation	Standard Deviation	% by Summation	Standard Deviation	% by Summation	Standard Deviation
Interstitial water	0.0009	--	0.001	--	0.009	--
Exchangeable	0.00	--	0.34	0.29	0.00	--
Easily reducible	3.12	0.63	0.84	0.47	1.66	1.01
Organic + sulfide	0.00	--	0.00	--	0.00	--
Moderately reducible	96.88	0.62	58.77	9.80	70.44	10.38
Residual	0.00	--	40.05	9.30	27.90	9.79
	100.00		100.00		100.00	
Total As by summation, $\mu\text{g/g}$	5.00		9.43		6.23	
Total As by digestion, $\mu\text{g/g}$	4.23		6.50		6.90	
% recovery by summation	118.2		145.0		90.3	

APPENDIX A: SEDIMENT AND WATER COLUMN CHARACTERISTICS

Table A1  
Physical and Chemical Characteristics of Mobile Bay Sediments

Site	Depth cm	Particle-Size Distribution, %			Cation Exchange Capacity meq/100 g	Total Organic Carbon %	In- organic Carbon %	Total Sulfides mg/g	Total Nitrogen mg/g	Solid Phase %	Liquid Phase %	Total Mercury µg/g
		<2µm	2-50µm	>50µm								
1	0-15	43.3	27.7	29.0	47.3	1.89	0.11	0.76	2.15	32.55	67.45	0.14
	15-30	40.3	30.7	29.0	43.2	1.71	0.16	1.33	2.10	38.50	61.50	0.12
	30-45	36.0	29.0	35.0	43.1	1.95	0.10	0.86	2.12	39.63	60.37	0.20
	45-60	50.3	33.0	15.7	49.8	1.94	0.12	1.00	2.03	40.15	59.85	0.20
2	0-15	58.0	30.3	11.7	58.0	2.08	0.04	0.98	2.16	30.05	69.95	0.19
	15-30	52.0	34.0	14.0	46.4	1.99	0.06	1.36	2.03	35.23	63.44	0.73
	30-45	53.7	34.7	11.7	47.0	1.95	0.05	1.21	2.05	36.68	63.32	0.46
	45-60	58.6	29.7	11.7	47.8	1.93	0.05	0.88	1.93	37.78	62.22	1.00
3	0-15	62.0	31.7	6.3	45.9	2.25	0.03	1.02	1.58	29.59	70.41	0.95
	15-30	59.3	37.0	3.7	43.8	2.19	0.08	0.72	1.49	31.44	68.56	0.83
	30-45	58.7	36.7	4.7	42.3	2.28	0.03	0.57	1.69	33.07	66.93	1.00
	45-60	59.3	35.7	5.0	40.7	2.25	0.05	0.53	1.52	35.02	64.98	0.43

Table A2  
Physical and Chemical Characteristics of Ashtabula, Ohio, Sediments

Site	Depth cm	Particle-Size Distribution, %		Cation Exchange Capacity meq/100 g	Total Organic Carbon %	In- organic Carbon %	Total Sulfides mg/g	Total Nitrogen mg/g	Solid Phase %	Liquid Phase %	Total Mercury µg/g
		<2µm	2-50µm >50µm								
1	0-15	35	65	23.3	1.59	0.04	0.13	1.63	58.1	41.9	0.24
	15-30	35	65	14.9	1.41	0.99	0.15	1.49	60.2	39.8	0.13
	30-45	36	58	18.7	1.65	0.52	0.19	1.41	58.9	41.1	0.25
	45-60	40	59	15.3	1.63	0.35	0.26	1.46	58.2	41.8	0.30
2	0-15	40	57	30.7	2.09	0.95	0.55	1.67	39.5	60.5	0.54
	15-30	47	5	33.7	2.42	0.86	0.44	1.49	35.8	64.1	0.40
	30-45	44	56	28.7	1.62	1.21	0.48	1.46	45.0	55.0	1.01
	45-60	45	55	30.2	1.61	1.39	0.57	1.37	42.2	57.8	1.01
3	0-15	34	66	14.5	3.44	0.25	0.26	1.63	56.3	43.7	1.03
	15-30	34	63	18.4	3.55	0.19	0.23	1.50	55.0	45.0	0.52
	30-45	35	63	18.5	3.33	0.60	0.19	1.55	50.0	50.0	0.73
	45-60	36	63.5	20.9	3.23	0.84	0.25	1.48	48.6	51.3	0.49
4	0-15	34	65	9.8	3.36	0.49	0.13	1.46	62.4	37.6	1.27
	15-30	34	63	8.4	4.24	0.79	0.08	1.50	64.3	35.6	1.00
	30-45	31	62	10.0	3.61	0.23	0.07	1.37	64.3	35.6	0.41
	45-60	35	63	11.5	3.46	0.06	0.09	1.42	63.2	36.8	0.51
5	0-15	33	67	7.4	2.09	0.00	0.15	0.91	65.8	34.1	0.55
	15-30	30	70	5.5	1.60	0.21	0.13	0.83	68.6	31.4	0.33
	30-45	30	70	8.8	1.61	0.37	0.19	1.12	65.1	34.9	0.46
	45-60	32	68	9.4	0.96	0.93	0.19	1.14	63.3	36.7	1.04

Table A3  
Physical and Chemical Characteristics of Bridgeport, Conn., Sediments

Site	Depth cm	Particle-Size Distribution, %			Cation Exchange Capacity meq/100 g	Total Organic Carbon %	In- organic Carbon %	Total Sulfides mg/g	Free Sulfides mg/g	Total Nitrogen mg/g	Solid Phase %	Liquid Phase %	Total Mercury µg/g
		<2µm	2-50µm	>50µm									
1	0-15	35.0	52.5	12.5	22.0	2.01	1.27	2.63	--	2.86	39.4	60.6	0.50
	15-30	36.5	46.5	17.0	21.2	1.56	1.16	2.36	--	2.73	42.5	57.5	0.47
	30-45	36.5	51.0	12.5	20.5	1.65	1.19	1.83	0.120	2.57	43.5	56.5	0.45
	45-60	43.0	57.0	0.0	24.4	1.65	1.31	2.66	0.050	2.99	38.8	61.2	0.51
2	0-15	46.5	52.5	1.0	27.8	2.25	0.56	0.78	0.008	2.50	41.6	58.4	1.33
	15-30	42.5	55.0	0.0	24.3	1.97	1.35	1.08	0.024	2.62	39.2	60.8	0.77
	30-45	41.5	58.5	8.5	29.4	1.79	1.57	0.52	0.075	2.63	37.9	61.1	0.53
	45-60	43.0	48.5	0.0	24.3	2.02	1.26	1.20	0.030	2.59	41.4	58.6	0.71
3	0-15	31.5	68.5	0.0	27.4	2.58	2.85	4.15	0.045	3.48	32.5	67.5	1.25
	15-30	38.0	62.0	0.0	26.9	1.61	3.97	4.27	0.105	3.52	34.4	65.6	1.03
	30-45	41.5	58.5	0.0	23.3	1.55	3.75	2.97	0.220	2.95	35.0	65.0	1.50
	45-60	43.5	55.5	1.0	18.9	2.07	2.41	1.68	0.050	2.70	42.0	58.0	1.71
4	0-15	26.5	72.5	1.0	20.6	2.14	3.80	3.22	0.035	3.21	36.7	63.3	1.03
	15-30	35.5	58.5	5.0	17.3	2.52	2.90	2.92	0.030	2.91	36.5	63.5	1.04
	30-45	40.0	58.0	2.0	27.8	2.31	3.90	0.89	0.030	2.90	40.3	59.7	1.01
	45-60	41.5	55.0	3.5	22.4	2.45	2.57	0.89	0.035	2.52	43.5	56.5	0.04
5	0-15	29.0	67.5	3.5	26.4	6.02	1.30	4.72	0.150	4.52	32.4	67.6	2.50
	15-30	38.0	62.0	0.0	25.7	4.67	2.03	5.39	0.160	4.60	31.0	69.0	1.83
	30-45	36.5	62.5	1.0	23.5	4.38	1.86	5.03	0.080	3.85	32.8	67.2	1.85
	45-60	39.0	61.0	0.0	24.5	6.64	2.90	4.42	0.210	3.38	37.6	62.4	2.45

Table A4  
Physical and Physicochemical Properties  
of Surface Sediments (0-4 cm)

<u>Site</u>	<u>Mobile Bay</u>	<u>Ashtabula</u>	<u>Bridgeport</u>
<u>Temperature, °C</u>			
1	17.0	23.8	12.5
2	17.0	21.5	16.0
3	17.0	23.0	15.0
4	-	19.9	15.0
5	-	21.5	16.0
<u>Redox Potential, mV</u>			
1	-225	-100	-150
2	-150	-	-200
3	-185	-110	-100
4	-	-	-
5	-	-100	-125
<u>pH</u>			
1	7.1	6.3	7.1
2	6.9	6.8	6.7
3	6.7	6.5	7.0
4	-	6.4	6.8
5	-	6.7	6.6

Table A5  
Physical and Chemical Properties of the Water  
Column at Site 1, Mobile Bay, Ala.

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm	pH
0.0	1.16	1.00	13.7	10.8	5.8
0.5	1.29	1.02	13.5	10.8	5.8
1.5	1.48	1.24	13.5	10.6	5.8
2.0	1.26	1.27	13.5	10.7	5.7
2.5	1.62	1.27	13.5	10.8	5.7
3.0	1.54	1.24	13.5	10.9	6.0
3.5	1.57	1.25	13.5	10.8	6.0
4.0	1.60	1.29	13.5	10.7	5.8
4.5	1.77	1.41	13.4	10.8	6.0
5.0	1.83	1.45	13.5	10.8	6.0
5.5	1.84	1.49	13.5	10.8	6.0
6.0	2.24	1.80	13.5	10.8	5.9
6.5	5.05	4.02	13.6	10.8	6.0
7.0	6.54	5.45	13.7	10.8	6.1
7.5	17.99	13.88	14.8	10.0	6.0
8.0	15.42	11.79	14.9	3.6	6.1

Table A6  
Physical and Chemical Properties of the Water Column  
at Site 1, Ashtabula, Ohio

<u>Depth</u> <u>m</u>	<u>Conductivity</u> <u>mmhos</u>	<u>Salinity</u> <u>ppt</u>	<u>Temperature</u> <u>°C</u>	<u>Dissolved O<sub>2</sub></u> <u>ppm</u>	<u>pH</u>
0.0	1.29	0.77	27.4	7.5	7.6
0.5	1.38	0.79	27.3	7.3	7.6
1.0	1.80	1.06	27.1	6.6	7.5
1.5	2.01	1.21	26.9	6.1	7.5
2.0	1.89	1.15	26.4	5.1	7.4
2.5	1.76	1.09	25.6	3.0	7.3
3.0	1.73	1.07	25.4	1.3	7.1

Table A7  
Physical and Chemical Properties of the Water Column  
at Site 2, Ashtabula, Ohio

<u>Depth</u> <u>m</u>	<u>Conductivity</u> <u>mmhos</u>	<u>Salinity</u> <u>ppt</u>	<u>Temperature</u> <u>°C</u>	<u>Dissolved O<sub>2</sub></u> <u>ppm</u>	<u>pH</u>
0.0	1.52	0.89	26.0	6.3	6.8
0.5	1.50	0.93	26.0	6.2	6.8
1.5	1.51	0.93	26.0	6.2	7.0
2.3	1.50	0.92	26.9	6.0	7.1
3.0	1.62	0.99	25.7	3.6	7.1
3.5	1.78	1.08	25.8	2.7	7.0
4.2	1.66	1.03	25.7	2.1	7.1

Table A8  
Physical and Chemical Properties of the Water Column  
at Site 3, Ashtabula, Ohio

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm	pH
0.0	1.57	0.95	26.8	6.7	8.0
1.0	0.90	0.54	25.7	5.9	8.0
2.0	0.56	0.36	23.8	5.4	8.0
3.0	0.50	0.33	23.6	5.2	7.9
4.0	0.51	0.34	23.6	5.0	7.8
5.0	0.49	0.32	23.5	4.7	7.8

Table A9  
Physical and Chemical Properties of the Water Column  
at Site 4, Ashtabula, Ohio

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm	pH
0.0	1.01	0.62	25.5	6.5	7.9
1.0	0.96	0.61	25.4	6.5	7.9
2.0	0.65	0.40	24.5	6.2	8.0
3.0	0.53	0.33	23.8	6.0	7.9
4.0	0.48	0.31	23.6	6.0	7.8
5.0	0.45	0.27	23.5	6.2	7.8
6.0	0.41	0.27	23.5	6.6	7.9
7.0	0.41	0.27	23.4	6.5	7.9
8.0	0.39	0.25	23.3	6.1	7.8

Table A10  
Physical and Chemical Properties of the Water Column  
at Site 5, Ashtabula, Ohio

<u>Depth</u> <u>m</u>	<u>Conductivity</u> <u>mmhos</u>	<u>Salinity</u> <u>ppt</u>	<u>Temperature</u> <u>°C</u>	<u>Dissolved O<sub>2</sub></u> <u>ppm</u>	<u>pH</u>
0.0	0.36	0.24	23.8	8.6	7.6
1.0	0.35	0.24	23.8	8.6	7.2
1.5	0.36	0.23	23.8	8.7	7.7
2.0	0.36	0.24	23.8	8.7	7.8
2.5	0.35	0.23	23.7	8.6	7.8
3.0	0.35	0.23	23.7	8.6	7.9
3.5	0.33	0.22	23.6	8.6	7.9
4.0	0.33	0.22	23.5	8.5	8.0
4.5	0.33	0.21	23.5	8.4	7.9
5.0	0.33	0.21	23.4	8.0	8.1
5.5	0.32	0.21	23.2	7.8	8.0
6.0	0.33	0.22	23.3	7.6	8.1
7.0	0.34	0.22	23.3	7.5	8.1
8.0	0.32	0.22	23.1	7.3	8.1

Table A11  
Physical and Chemical Properties of the Water Column  
at Site 1, Bridgeport, Conn.

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm
0.0	26.6	26.5	14.4	8.2
2.0	32.8	26.5	14.5	7.9
3.0	33.1	26.7	14.5	7.8
4.0	33.6	26.8	14.4	7.8
4.5	33.7	26.9	15.0	7.8
5.5	33.7	26.9	15.2	—
6.0	33.7	26.9	15.1	7.8
7.0	34.3	27.1	15.3	7.8
8.0	34.2	27.1	15.3	7.8
9.0	34.2	27.1	15.3	7.8
10.0	34.0	27.1	15.0	7.8
11.0	34.0	27.1	15.0	7.8
12.0	34.0	27.1	14.9	7.8

Table A12  
Physical and Chemical Properties of the Water Column  
at Site 2, Bridgeport, Conn.

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm
0	--	--	--	8.0
1	32.8	26.4	14.7	7.8
2	32.7	26.3	14.7	7.8
3	32.7	26.5	14.5	7.6
4	33.1	26.5	14.4	7.5
5	33.5	26.7	15.0	7.5
6	33.0	26.6	14.5	7.0

Table A13  
Physical and Chemical Properties of the Water Column  
at Site 3, Bridgeport, Conn.

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm
0	--	--	--	8.0
1	32.67	26.46	14.39	7.8
2	32.60	26.41	14.26	7.7
3	32.36	26.36	14.02	7.6
4	32.62	26.56	14.11	7.2

Table A14  
Physical and Chemical Properties of the Water Column  
at Site 4, Bridgeport, Conn.

Depth m	Conductivity mmhos	Salinity ppt	Temperature °C	Dissolved O <sub>2</sub> ppm
0	--	--	--	8.5
1	33.73	26.9	17.0	8.4
2	34.30	26.6	16.3	8.4
3	33.80	26.8	15.5	8.2
4	34.00	26.9	15.4	8.2
5	34.00	26.9	15.4	8.1
6	34.00	26.9	15.4	8.1
7	34.20	27.0	15.4	8.0
8	34.40	27.2	15.5	8.0
9	34.40	27.2	15.5	8.0
10	34.40	27.2	15.5	7.8

Table A15  
Physical and Chemical Properties of the Water Column  
at Site 5, Bridgeport, Conn.

<u>Depth</u> <u>m</u>	<u>Conductivity</u> <u>mmhos</u>	<u>Salinity</u> <u>ppt</u>	<u>Temperature</u> <u>°C</u>	<u>Dissolved O<sub>2</sub></u> <u>ppm</u>
0	--	--	--	8.8
1	34.48	27.16	16.0	8.6
2	34.22	27.01	15.6	8.6
3	34.44	27.03	15.7	8.4
4	34.44	27.01	15.7	8.2
5	34.45	27.03	15.8	8.2
6	34.45	27.02	15.7	8.0
7	34.49	27.06	15.8	7.6
8	34.61	27.12	15.8	--

APPENDIX B: CHEMICAL CONCENTRATIONS AND PERCENT EXTRACTED  
IN THE VARIOUS CHEMICALLY EXTRACTED SEDIMENT PHASES

Table B1

Key to Abbreviations Used in Tables B2-B4

Variable Number	Code	Identification
1	IFe	Interstitial water iron
2	EFe	Exchangeable phase iron
3	HFe	Hydroxylamine hydrochloride reducible iron (easily reducible)
4	OFe	Organic + sulfide phase iron
5	DFe	Citrate-dithionite reducible iron (moderately reducible)
6	RFe	Residual iron
7	TFe	Total iron
8	IMn	Interstitial water manganese
9	EMn	Exchangeable manganese
10	HMn	Hydroxylamine hydrochloride reducible phase manganese
11	OMn	Organic + sulfide phase manganese
12	DMn	Citrate-dithionite reducible phase manganese
13	RMn	Residual manganese
14	TMn	Total manganese
15	IZn	Interstitial water zinc
16	EZn	Exchangeable zinc
17	HZn	Hydroxylamine hydrochloride reducible Zn
18	OZn	Organic + sulfide phase zinc
19	DZn	Citrate-dithionite reducible zinc
20	RZn	Residual zinc
21	TZn	Total zinc
22	ICu	Interstitial water copper
23	ECu	Exchangeable copper
24	HCu	Hydroxylamine hydrochloride reducible copper
25	OCu	Organic + sulfide phase copper
26	DCu	Citrate-dithionite reducible copper
27	RCu	Residual copper
28	TCu	Total copper
29	ICd	Interstitial water cadmium
30	ECd	Exchangeable cadmium
31	HCd	Hydroxylamine hydrochloride reducible cadmium
32	OCd	Organic + sulfide phase cadmium
33	DCd	Citrate-dithionite reducible cadmium
34	RCd	Residual cadmium
35	TCd	Total cadmium
36	IAs	Interstitial water arsenic
37	EAs	Exchangeable arsenic
38	HAs	Hydroxylamine hydrochloride reducible arsenic
39	OAs	Organic + sulfide phase arsenic
40	DAs	Citrate-dithionite reducible arsenic
41	RAs	Residual arsenic
42	TAs	Total arsenic

(Continued)

Table B1 (Concluded)

Variable Number	Code	Identification
43	INi	Interstitial water nickel
44	ENi	Exchangeable nickel
45	HNi	Hydroxylamine hydrochloride reducible nickel
46	ONi	Organic + sulfide phase nickel
47	DNi	Citrate-dithionate reducible nickel
48	RNi	Residual nickel
49	TNi	Total nickel
50	IPh	Interstitial water orthophosphate
51	INh	Interstitial water ammonium
52	ENh	Exchangeable ammonium

Table B2  
Mobile Bay, Ala., Chemical Fractionation

Site	Depth	Sediment Fraction											
		IFe mg/l	EFe µg/g	HFe µg/g	OFe µg/g	DFe µg/g	RFe µg/g	TFe µg/g	IMn mg/l	EMn µg/g	HMn µg/g	OMn µg/g	IMn µg/g
1	0-15	21.6	354	1142	3532	20,308	2527	43,633	21.48	138.62	324.63	380.78	64.25
	15-30	62.1	319	1280	3139	22,082	2361	49,683	16.51	84.73	116.22	262.78	45.91
	30-45	151.4	746	1081	3873	19,884	2444	41,450	15.20	62.17	115.88	345.42	49.34
	45-60	114.2	586	1021	3911	20,017	2465	44,733	10.36	44.32	102.42	346.63	54.98
2	0-15	18.9	605	1271	4205	22,729	2637	40,833	14.36	128.30	142.65	385.12	68.51
	15-30	76.7	541	1202	4100	22,419	2582	40,750	8.55	70.47	116.98	365.82	56.30
	30-45	70.5	662	1143	3943	22,635	2662	39,483	7.06	43.33	114.57	406.38	58.76
	45-60	58.5	459	948	4023	21,429	2740	41,850	6.35	36.42	144.03	454.90	61.28
3	0-15	24.4	357	1030	5922	20,658	2688	45,760	3.98	46.06	95.23	282.93	68.46
	15-30	26.2	277	835	5510	20,483	2597	43,670	4.20	41.68	80.62	314.40	58.13
	30-45	26.5	276	776	6248	20,608	2656	46,017	4.44	42.13	87.50	269.72	55.68
	45-60	25.8	273	701	5965	21,062	2711	40,700	4.55	39.22	85.85	270.90	55.87
		RMn µg/g	TMn µg/g	ICu µg/g	ECu µg/g	HCu µg/g	OCu µg/g	DCu µg/g	RCu µg/g	TCu µg/g	IZn µg/g	EZn µg/g	HZn µg/g
		µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
1	0-15	89.50	1074.33	1.217	--	0.00767	12.33	2.37	22.23	36.5	35.33	--	10.69
	15-30	80.99	795.67	1.617	--	0.01667	10.98	1.03	20.90	37.0	27.33	--	6.90
	30-45	93.33	696.67	1.933	--	0.01233	13.86	1.49	23.82	35.2	45.33	--	6.29
	45-60	95.50	685.67	1.900	--	0.01667	13.56	0.82	23.08	41.5	40.50	--	6.35
2	0-15	111.33	835.67	1.967	--	0.03433	17.00	0.98	25.50	33.0	15.67	--	7.80
	15-30	92.33	890.50	1.667	--	0.04333	16.18	1.78	27.17	33.5	44.00	--	5.16
	30-45	94.17	798.83	2.233	--	0.01300	15.33	1.15	28.83	36.8	34.00	--	4.40
	45-60	98.17	922.00	1.267	--	0.01033	14.68	1.06	30.00	31.0	18.00	--	2.73
3	0-15	141.67	555.33	2.250	--	0.02000	17.82	1.75	23.33	41.2	26.00	--	4.01
	15-30	123.33	558.80	2.267	--	0.02000	16.25	2.27	24.50	39.8	31.33	--	2.56
	30-45	127.83	586.67	1.333	--	0.01667	16.59	2.65	23.67	41.3	46.33	--	2.72
	45-60	133.67	522.50	1.000	--	0.00933	16.82	4.69	26.17	49.0	56.33	--	2.41
		OZn µg/g	DZn µg/g	RZn µg/g	TZn µg/g	INi µg/g	ENi µg/g	HMNi µg/g	ONi µg/g	DNi µg/g	RNi µg/g	TNi µg/g	
		µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	
1	0-15	133.75	--	--	256.7	4.5	0.250	1.56	6.21	--	107.6	148.0	
	15-30	156.48	--	--	306.7	13.3	0.923	2.62	6.69	--	106.6	204.8	
	30-45	129.53	--	--	248.3	1.3	0.195	6.49	9.57	--	132.5	137.2	
	45-60	139.25	--	--	213.3	6.3	0.560	2.30	8.08	--	133.2	141.0	
2	0-15	174.70	--	--	259.0	4.7	2.483	3.94	8.76	--	111.0	146.2	
	15-30	132.55	--	--	375.5	10.7	2.023	0.83	9.20	--	120.5	141.8	
	30-45	143.18	--	--	311.3	3.7	1.270	1.10	7.47	--	119.8	147.2	
	45-60	91.65	--	--	180.7	15.3	0.055	1.28	5.94	--	123.6	163.3	
3	0-15	104.38	--	--	176.7	51.3	--	1.61	8.76	--	105.6	151.0	
	15-30	100.97	--	--	146.3	218.0	--	0.99	8.46	--	107.8	166.3	
	30-45	107.55	--	--	148.7	252.3	--	1.07	8.85	--	114.3	144.5	
	45-60	71.50	--	--	188.3	430.3	--	1.97	10.06	--	112.8	183.2	
		ICd µg/g	ECd µg/g	HCd µg/g	OCd µg/g	DCd µg/g	RCd µg/g	TCd µg/g	IAS µg/g	EAS µg/g	HAS µg/g	OAS µg/g	
		µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	
1	0-15	<0.05	--	0.01967	0.477	--	4.53	3.1	9.63	--	0.143	--	
	15-30	<0.05	--	0.01400	0.427	--	4.72	2.8	7.00	--	0.118	--	
	30-45	<0.05	--	0.01867	0.673	--	3.08	4.0	3.00	--	0.145	--	
	45-60	<0.05	--	0.01067	0.613	--	2.58	2.7	3.67	--	0.143	--	
2	0-15	<0.05	--	0.03333	0.647	--	2.52	2.3	12.50	--	0.150	--	
	15-30	<0.05	--	0.02800	0.677	--	2.65	3.2	3.20	--	0.182	--	
	30-45	<0.05	--	0.03000	0.803	--	2.78	3.1	1.13	--	0.173	--	
	45-60	<0.05	--	0.01933	0.590	--	2.80	4.4	3.60	--	0.132	--	
3	0-15	<0.05	--	0.01633	0.727	--	2.14	4.7	8.00	--	0.182	--	
	15-30	<0.05	--	0.01067	0.547	--	2.25	5.0	1.20	--	0.179	--	
	30-45	<0.05	--	0.02800	0.577	--	2.12	5.5	0.80	--	0.155	--	
	45-60	<0.05	--	0.01700	0.550	--	2.20	2.7	1.60	--	0.132	--	
		DAs µg/g	RAAs µg/g	TAs µg/g	IPh mg/l	INh <sub>4</sub> mg/l	ENh <sub>4</sub> µg/g						
		µg/g	µg/g	µg/g	mg/l	mg/l	µg/g						
1	0-15	3.50	--	4.87	86.6	32.0	162.4						
	15-30	3.70	--	5.30	76.8	40.0	163.9						
	30-45	3.66	--	3.33	33.1	46.0	328.9						
	45-60	3.92	--	3.93	45.8	38.0	280.6						
2	0-15	4.35	--	4.63	77.3	23.0	99.9						
	15-30	4.23	--	4.47	67.6	27.0	131.2						
	30-45	5.02	--	5.07	59.0	24.3	138.1						
	45-60	5.24	--	4.37	67.5	24.3	141.3						
3	0-15	6.26	--	3.23	45.6	10.8	69.2						
	15-30	6.03	--	3.17	44.6	10.3	65.0						
	30-45	5.93	--	3.50	37.8	10.3	65.6						
	45-60	6.39	--	3.20	36.0	10.7	66.3						

Table B3  
Ashtabula, Ohio, Chemical Fractionation

Site	Depth	Sediment Fraction											
		IFe	EFe	HFe	OFe	DFe	RFe	TFe	IMn	EMn	HMn	OMn	
		mg/g	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	mg/g	VE/R	VE/R	VE/R	
1	0-15	110.0	800.4	994.0	1076.5	11,500.0	22,500	36,450	9.41	64.0	92.7	171.3	
	15-30	85.0	695.5	1116.0	1494.5	11,996.5	25,375	38,250	5.46	35.4	97.0	196.9	
	30-45	72.5	565.7	785.5	1841.0	13,408.5	23,750	39,250	1.48	13.9	49.9	318.7	
	45-60	60.0	581.9	622.5	908.5	13,178.0	25,000	40,900	1.14	13.6	53.3	304.5	
2	0-15	30.0	588.7	262.5	851.5	17,089.5	23,750	41,800	2.39	44.3	151.3	420.4	
	15-30	35.0	725.2	33.0	992.5	17,450.5	28,250	44,000	2.61	49.7	130.8	208.5	
	30-45	42.5	577.8	135.5	1272.0	21,257.0	24,750	68,450	2.03	31.0	99.5	304.4	
	45-60	55.0	766.8	30.5	817.5	15,544.5	20,175	41,100	2.08	28.9	53.4	198.7	
3	0-15	55.0	523.8	301.0	1419.0	16,088.5	23,375	42,750	2.70	29.4	75.8	258.0	
	15-30	60.0	472.6	287.5	929.5	13,898.0	24,375	42,050	2.55	24.3	90.7	274.9	
	30-45	65.0	372.9	116.5	911.5	15,055.5	24,875	44,100	2.87	27.4	122.2	449.8	
	45-60	67.5	522.3	108.5	809.0	10,182.0	19,625	41,450	2.49	25.1	96.0	258.3	
4	0-15	45.0	357.6	127.5	655.0	14,172.5	23,500	39,000	3.22	22.3	63.8	274.0	
	15-30	60.0	366.3	66.0	780.0	12,655.0	22,125	35,700	3.94	22.6	62.1	242.0	
	30-45	45.0	343.4	207.5	756.0	14,880.5	26,250	40,000	2.37	15.0	98.2	325.6	
	45-60	52.5	386.6	224.5	907.0	13,775.0	30,375	37,000	0.98	8.0	64.6	359.0	
5	0-15	25.0	401.6	109.0	545.0	10,862.0	24,500	41,000	3.42	25.1	56.7	189.2	
	15-30	45.0	415.8	97.0	753.0	12,516.5	28,875	41,350	4.13	28.5	62.9	205.8	
	30-45	40.0	523.7	131.5	688.0	12,328.0	21,875	42,700	3.63	28.3	57.7	202.4	
	45-60	31.5	440.8	81.0	484.0	13,111.0	28,625	48,700	2.87	24.4	48.0	183.3	
		DMn	RMn	TMn	ICu	ECu	HCu	OCu	DCu	RCu	TCu	IZn	
		VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	mg/g	
1	0-15	20.8	179.5	515	1.30	--	0.020	11.4	--	8.0	31.0	1.55	
	15-30	18.0	200.0	495	0.30	--	--	17.6	--	8.7	33.5	0.29	
	30-45	16.7	184.8	570	0.25	--	0.025	23.3	--	10.0	33.5	0.51	
	45-60	28.0	212.0	585	0.25	--	--	19.0	--	8.4	33.0	0.09	
2	0-15	211.3	215.5	765	0.15	--	0.080	26.5	0.460	16.3	48.5	0.46	
	15-30	415.0	230.5	1185	0.10	--	0.105	32.0	0.925	19.2	46.0	1.13	
	30-45	446.0	229.0	1180	0.15	--	0.080	48.2	1.645	19.0	70.5	2.59	
	45-60	108.3	200.0	725	0.10	--	0.040	33.9	--	14.8	43.0	4.27	
3	0-15	61.2	167.0	510	0.10	--	--	24.1	1.425	12.5	39.5	0.19	
	15-30	23.4	184.3	560	0.10	--	--	29.0	1.870	11.0	41.5	1.04	
	30-45	44.4	179.3	795	0.15	--	0.010	23.8	1.030	12.3	48.5	0.24	
	45-60	29.1	158.8	565	0.10	--	0.015	17.1	1.950	18.0	40.0	0.08	
4	0-15	25.8	188.3	485	0.20	--	--	16.7	2.000	10.8	37.0	0.12	
	15-30	42.5	197.8	590	0.20	--	0.010	12.7	3.285	13.8	36.0	0.43	
	30-45	27.7	209.5	535	0.15	--	--	19.8	1.705	12.3	36.5	0.89	
	45-60	14.2	213.5	530	0.30	--	0.005	18.9	2.550	8.7	31.5	0.42	
5	0-15	41.0	220.0	570	0.15	--	--	13.1	1.190	11.0	40.5	1.00	
	15-30	56.9	235.3	550	0.30	--	--	13.2	2.565	12.5	39.5	1.27	
	30-45	62.9	219.5	585	0.30	--	--	17.8	3.120	10.5	37.0	1.35	
	45-60	75.5	221.5	550	0.35	--	--	25.7	3.635	15.0	51.0	0.54	
		EZn	HZn	OZn	DZn	RZn	TZn	INi	ENi	HNi	ONi	DNi	
		VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	VE/R	
1	0-15	0.98	37.5	242	177.5	--	223	0.060	1.20	1.78	10.0	35.0	
	15-30	0.73	36.0	212	116.0	--	378	0.040	1.61	2.55	11.7	41.0	
	30-45	0.64	15.5	104	116.5	--	265	0.025	1.87	2.06	19.7	37.0	
	45-60	4.44	22.9	44	189.0	--	240	0.015	1.87	2.22	16.6	38.0	
2	0-15	1.95	19.9	156	52.5	--	415	0.025	1.33	0.72	21.1	51.2	
	15-30	5.75	44.6	75	94.0	--	430	0.035	1.31	0.55	19.0	67.4	
	30-45	5.26	10.0	96	75.0	--	440	0.035	1.50	0.75	47.6	74.3	
	45-60	9.45	17.5	80	76.0	--	560	0.035	1.26	1.81	26.7	46.8	
3	0-15	--	22.7	220	96.5	--	310	0.045	1.18	6.46	18.9	49.0	
	15-30	--	30.1	257	62.0	--	440	0.050	1.84	4.89	28.6	38.8	
	30-45	--	21.2	211	413.5	--	1,475	0.070	1.57	2.86	24.7	43.1	
	45-60	--	11.4	291	210.5	--	720	0.065	1.47	1.93	18.8	43.3	
4	0-15	--	10.1	152	89.0	--	360	0.045	0.53	4.70	16.7	35.9	
	15-30	--	25.9	184	122.5	--	655	0.045	0.48	2.41	9.9	35.5	
	30-45	--	28.0	180	76.5	--	380	0.040	0.43	1.76	16.3	37.6	
	45-60	--	19.2	158	117.0	--	310	0.030	1.31	1.22	21.8	33.5	
5	0-15	--	15.2	138	84.5	--	285	0.030	0.77	5.55	7.5	34.9	
	15-30	--	10.7	181	84.5	--	265	0.015	0.79	7.75	7.5	38.2	
	30-45	--	17.6	188	129.0	--	250	0.885	1.14	6.34	9.1	41.1	
	45-60	--	22.8	263	64.5	--	480	0.020	1.17	3.23	12.9	37.5	

(Continued)

Table B3 (Concluded)

Site	Depth	RNi µg/g	TNi µg/g	ICd µg/l	ECd µg/g	HCd µg/g	OCd µg/g	DCd µg/g	PCd µg/g	TCd µg/g	IAS µg/l	EAs µg/l
1	0-15	100.5	117.0	0.70	--	0.065	1.00	--	0.15	5.0	26.3	0.085
	15-30	122.5	149.0	0.50	--	0.016	1.14	--	0.25	1.5	20.2	0.065
	30-45	110.5	120.0	0.60	--	0.115	2.57	--	0.35	4.0	24.9	0.080
	45-60	121.0	193.5	0.40	--	0.100	2.34	--	0.50	1.8	14.5	0.020
2	0-15	120.0	261.0	0.35	--	0.175	5.91	--	1.90	4.5	6.3	0.006
	15-30	152.5	248.0	0.50	--	0.370	8.27	--	2.90	6.5	7.6	0.003
	30-45	152.5	290.0	0.70	--	0.425	7.52	--	1.60	6.5	6.2	0.008
	45-60	147.5	211.5	2.50	--	0.200	5.47	--	2.70	4.0	5.1	0.001
3	0-15	130.5	214.5	0.40	--	0.095	4.38	--	1.30	3.5	4.5	0.015
	15-30	114.0	193.0	0.10	--	0.215	5.55	--	0.80	5.0	5.8	0.010
	30-45	121.5	218.0	0.20	--	0.865	6.38	--	0.55	10.5	2.6	0.010
	45-60	140.0	197.0	0.05	--	0.345	3.42	--	2.10	4.5	2.5	0.005
4	0-15	114.0	257.0	0.45	--	0.025	1.98	--	0.20	5.0	14.4	0.035
	15-30	115.0	224.0	0.05	--	0.050	2.18	--	0.85	4.5	10.0	0.040
	30-45	105.5	198.5	0.30	--	0.080	2.92	--	0.45	2.5	7.6	0.020
	45-60	105.0	201.0	0.20	--	0.040	3.02	--	0.55	3.0	8.6	0.020
5	0-15	105.5	236.5	0.25	--	0.045	1.68	--	0.25	2.0	17.1	0.055
	15-30	115.5	220.5	1.00	--	0.130	1.97	--	0.40	3.0	29.2	0.070
	30-45	106.5	245.5	6.70	--	0.030	2.90	--	1.15	2.0	5.6	0.050
	45-60	124.0	262.0	1.00	--	0.050	2.78	--	0.70	3.5	5.7	0.040
		HAs µg/g	OAs µg/g	DAAs µg/g	RAAs µg/g	TAs µg/g	IPh mg/l	INh mg/l	ENh µg/g			
1	0-15	0.092	--	4.26	4.00	6.04	1.05	84.0	147.4			
	15-30	0.059	--	4.92	4.15	5.94	0.50	77.0	144.5			
	30-45	0.091	--	5.72	4.20	7.65	0.50	77.5	141.3			
	45-60	0.071	--	5.67	4.10	7.15	0.40	78.5	149.0			
2	0-15	0.037	--	7.53	3.10	11.02	0.10	53.0	124.8			
	15-30	0.044	--	7.91	3.10	11.70	0.10	57.0	72.4			
	30-45	0.048	--	8.08	2.80	9.35	0.10	60.0	119.8			
	45-60	0.039	--	5.60	3.30	5.60	0.10	63.5	135.9			
3	0-15	0.058	--	5.71	2.90	6.45	0.25	55.0	101.4			
	15-30	0.044	--	6.12	2.70	6.35	0.20	69.5	115.9			
	30-45	0.043	--	6.75	2.50	6.65	0.125	78.0	125.8			
	45-60	0.042	--	3.83	3.00	6.20	0.15	74.0	126.1			
4	0-15	0.091	--	4.54	5.25	3.90	0.50	44.5	85.8			
	15-30	0.066	--	4.01	2.35	4.05	0.60	66.5	93.9			
	30-45	0.114	--	5.67	2.95	4.25	0.25	63.5	99.7			
	45-60	0.060	--	5.61	4.70	6.00	0.20	72.5	121.2			
5	0-15	0.126	--	3.90	5.45	4.60	1.30	25.5	56.0			
	15-30	0.094	--	5.47	5.25	4.90	0.90	46.0	79.1			
	30-45	0.142	--	5.52	5.60	6.05	0.90	57.5	103.3			
	45-60	0.204	--	4.17	4.10	6.30	0.80	60.0	128.8			

Table B4  
Bridgeport, Conn., Chemical Fractionation

Site	Depth	Sediment Fraction										
		IFe mg/l	EFe µg/g	HFe µg/g	OFe µg/g	DFe µg/g	RFe µg/g	TFe µg/g	IMn mg/l	EMn µg/g	HMn µg/g	OMn µg/g
1	0-15	0.915	28.5	558.5	3713	12,206	22,125	35,300	1.845	9.80	34.53	166.0
	15-30	0.500	7.0	724.0	3956	13,961	22,250	33,700	1.005	4.36	20.85	161.0
	30-45	0.200	6.4	458.0	3681	9,432	20,125	34,150	0.740	2.42	17.77	146.5
	45-60	0.115	9.2	583.0	2860	12,648	22,500	37,650	1.230	6.88	36.06	228.5
2	0-15	0.265	8.1	399.0	5415	17,338	23,500	41,650	0.410	2.34	7.57	226.0
	15-30	0.145	35.7	422.5	5926	16,519	23,375	48,000	0.020	0.37	7.90	240.0
	30-45	0.250	0.4	281.5	3851	13,872	25,125	42,950	0.040	0.39	6.23	178.5
	45-60	0.400	0.6	561.5	3291	15,522	22,750	41,700	0.030	0.31	6.23	182.5
3	0-15	0.530	0.4	1179.0	2939	12,864	22,250	45,900	0.025	0.06	5.35	110.5
	15-30	0.595	1.1	1484.0	2995	17,289	22,750	48,050	0.020	0.02	3.64	115.0
	30-45	0.665	1.1	1140.5	5015	18,945	22,250	43,200	0.025	0.02	5.77	183.0
	45-60	0.595	0.7	708.5	3580	14,533	21,750	46,850	0.030	0.03	5.14	144.5
4	0-15	0.145	15.2	1109.0	3480	17,086	24,125	41,850	0.030	0.64	17.55	190.0
	15-30	0.130	11.3	1058.5	3538	14,674	22,175	37,950	0.030	0.31	8.72	178.5
	30-45	0.260	0.2	1075.5	3936	15,211	22,875	41,750	0.030	0.25	9.06	254.5
	45-60	0.125	1.1	559.0	3130	13,813	23,875	43,350	0.100	0.07	10.60	278.0
5	0-15	0.110	0.8	1427.0	3624	14,646	24,500	44,450	0.090	0.77	18.63	133.5
	15-30	0.205	0.4	1440.5	3286	16,826	24,250	59,800	0.045	0.76	15.00	141.5
	30-45	0.110	2.6	2084.5	3421	17,035	25,625	47,300	0.040	0.36	16.32	162.5
	45-60	0.155	3.8	810.5	3404	18,455	23,750	68,150	0.040	0.44	13.61	207.5
		DMn µg/g	RMn µg/g	TMn µg/g	ICu µg/g	ECu µg/g	HCu µg/g	OCu µg/g	DCu µg/g	RCu µg/g	TCu µg/g	IZn µg/g
1	0-15	26.9	345	530	12.5	--	0.030	681	5.92	60.0	515	300
	15-30	25.1	358	565	14.0	--	0.100	664	2.80	62.8	560	340
	30-45	18.3	358	575	15.0	--	0.120	552	1.85	52.8	485	1060
	45-60	25.1	383	505	11.0	--	0.095	627	2.90	71.0	560	240
2	0-15	20.9	495	515	5.5	--	0.145	783	3.70	55.5	600	1570
	15-30	18.1	520	585	5.5	--	0.115	690	7.65	49.3	660	350
	30-45	19.6	458	580	3.5	--	0.040	367	4.95	46.8	477	3555
	45-60	20.7	508	610	3.5	--	0.125	713	7.55	65.0	675	485
3	0-15	20.0	408	490	4.5	--	0.200	1,320	4.45	106.5	1455	105
	15-30	18.8	385	470	4.5	--	0.045	1,320	4.95	96.3	1265	50
	30-45	21.7	343	400	21.0	--	0.075	1,760	5.75	104.0	1325	825
	45-60	15.8	388	545	12.0	--	0.140	1,300	2.85	89.0	1295	45
4	0-15	21.0	318	510	8.0	--	0.030	1,447	7.50	124.8	1205	380
	15-30	20.4	300	460	4.5	--	0.050	1,324	3.65	99.3	1090	1025
	30-45	28.5	278	550	5.0	--	0.035	1,396	2.25	107.8	1220	1290
	45-60	27.1	350	630	7.5	--	0.090	1,898	2.95	64.3	897	690
5	0-15	21.2	313	465	7.5	--	0.040	1,789	5.71	148.3	1555	65
	15-30	18.3	275	550	9.5	--	0.140	1,956	0.06	145.5	2265	108
	30-45	17.9	360	475	13.5	--	0.015	1,915	1.70	153.0	1600	73
	45-60	21.7	323	620	10.5	--	0.005	2,012	--	153.8	2550	163
		EZn g/l	HZn µg/g	OZn µg/g	DZn µg/g	RZn µg/g	TZn µg/g	INi µg/g	ENi µg/g	HNi µg/g	ONi µg/g	DNi µg/g
1	0-15	0.48	71.1	555	176	--	480	17.0	0.020	1.78	30.4	1.490
	15-30	1.45	65.0	224	347	--	580	16.5	0.031	2.56	33.4	0.520
	30-45	0.59	72.1	138	157	--	2,050	8.0	0.030	2.07	24.2	0.895
	45-60	5.14	85.1	282	450	--	435	15.5	0.036	2.23	25.3	0.425
2	0-15	0.08	117.9	553	377	--	470	6.5	--	0.72	28.1	--
	15-30	8.20	67.1	274	363	--	575	14.0	--	0.56	28.3	--
	30-45	0.38	57.5	507	212	--	670	12.5	--	0.75	18.6	--
	45-60	0.92	99.5	535	143	--	620	4.0	0.025	1.81	39.0	0.125
3	0-15	8.32	366.2	858	243	--	1,170	22.0	0.035	6.47	80.9	1.040
	15-30	1.46	170.5	471	170	--	3,325	4.0	0.095	4.90	68.8	0.355
	30-45	2.76	174.3	501	43	--	1,110	4.0	0.155	2.86	64.0	0.560
	45-60	3.07	143.0	722	334	--	1,035	4.0	0.040	1.94	37.0	--
4	0-15	4.69	151.5	495	127	--	840	9.5	0.035	4.70	52.7	0.880
	15-30	3.54	163.0	1030	59	--	980	6.5	0.030	2.41	43.1	0.215
	30-45	9.77	168.1	1127	83	--	825	4.5	0.035	1.77	31.8	0.210
	45-60	9.03	136.7	707	264	--	710	12.0	0.005	1.22	53.0	--
5	0-15	1.07	143.0	605	90	--	890	21.0	0.050	5.56	73.4	2.100
	15-20	2.42	125.0	503	--	--	1,500	16.0	0.165	7.75	71.0	3.400
	30-45	4.78	202.0	572	27	--	1,135	12.5	0.085	6.34	48.2	1.910
	45-60	0.60	222.0	709	--	--	1,935	20.5	0.030	3.24	81.7	2.040

(Continued)

Table B4 (Concluded)

Site	Depth	RNI µg/g	TNI µg/g	ICd µg/l	ECd µg/g	HCd µg/g	OCd µg/g	DCd µg/g	RCd µg/g	TCd µg/g	IAs µg/l	EAs µg/g
1	0-15	136.3	205	26.5	--	0.155	7.90	--	--	9.0	25.2	--
	15-30	132.5	175	28.0	--	0.360	7.29	--	--	10.0	14.2	--
	30-45	129.8	145	27.0	--	0.155	5.21	--	--	8.5	7.0	--
	45-60	141.0	170	19.0	--	0.335	5.04	--	--	7.5	32.8	--
2	0-15	128.5	180	24.5	--	0.375	3.99	--	--	7.0	2.4	--
	15-30	124.3	170	24.0	--	0.465	4.42	--	--	8.5	5.3	--
	30-45	131.5	150	32.5	--	0.240	3.02	--	--	7.5	7.7	--
	45-60	133.3	180	26.0	--	0.490	12.30	--	--	14.5	32.8	--
3	0-15	158.8	260	25.5	--	3.390	53.45	--	--	61.5	25.5	--
	15-30	151.0	220	25.0	--	0.925	48.65	--	--	64.0	35.5	--
	30-45	135.0	180	27.0	--	0.915	36.35	--	--	33.5	4.5	--
	45-60	134.3	195	27.5	--	0.760	12.35	--	--	20.0	6.5	--
4	0-15	125.3	185	29.0	--	0.395	10.90	--	--	13.0	4.5	--
	15-30	109.3	195	22.0	--	0.335	9.50	--	--	11.0	4.0	--
	30-45	116.5	205	13.0	--	0.445	7.65	--	--	9.5	26.0	--
	45-60	129.0	230	9.0	--	0.190	6.10	--	--	7.0	14.0	--
5	0-15	135.3	225	14.5	--	0.355	15.17	--	--	14.5	128.5	--
	15-30	109.5	320	8.0	--	0.175	17.19	--	--	20.5	132.0	--
	30-45	113.0	210	5.5	--	0.545	12.23	--	--	11.0	148.0	--
	45-60	91.8	265	3.5	--	0.370	12.95	--	--	14.0	33.5	--
		HAs µg/g	OAs µg/g	DAs µg/g	RAs µg/g	TAs µg/g	IPh mg/l	INh mg/l	ENh µg/g			
1	0-15	0.050	--	3.95	0.58	5.0	87	10.2	262.7			
	15-30	0.070	--	3.46	0.53	4.6	104	11.9	284.5			
	30-45	0.030	--	3.23	0.68	3.7	92	10.3	233.8			
	45-60	0.035	--	4.41	0.60	6.8	71	8.4	255.7			
2	0-15	0.105	--	4.42	1.28	4.1	65	7.6	209.7			
	15-30	0.165	--	2.72	1.65	5.9	75	7.9	320.6			
	30-45	0.105	--	1.80	1.55	4.8	71	7.5	285.5			
	45-60	0.090	--	1.95	1.15	7.5	70	7.2	229.8			
3	0-15	0.050	--	4.63	2.45	8.6	45	3.8	160.8			
	15-30	0.080	--	4.96	2.40	7.1	60	5.5	225.6			
	30-45	0.085	--	6.01	2.25	7.0	67	6.8	307.8			
	45-60	0.065	--	3.96	2.05	6.9	68	7.0	244.9			
4	0-15	0.130	--	3.83	2.03	5.7	37	3.6	127.5			
	15-30	0.180	--	3.81	2.60	7.0	56	5.0	231.2			
	30-45	0.155	--	5.46	2.18	7.4	64	7.1	276.4			
	45-60	0.205	--	3.56	2.10	10.2	42	8.4	302.3			
5	0-15	0.055	--	4.28	1.90	5.6	65	6.1	246.5			
	15-30	0.115	--	9.34	1.50	12.2	60	6.5	292.4			
	30-45	0.130	--	6.75	2.55	9.2	62	7.0	333.6			
	45-60	0.065	--	6.65	2.60	8.8	63	7.7	308.9			

Table B5  
Nutrient and Heavy Metal Concentration of Dredging  
Site Water, Mobile Bay, Ala.

<u>Parameter Measured</u>	<u>Dredging Site Water Concentration, <math>\mu\text{g}/\text{l}</math></u>		
	<u>Site</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
Ammonium-N	<2.0	<2.0	<2.0
Nitrate + nitrite-N	435	442	265
Orthophosphate	<3.0	<3.0	<3.0
Mercury	0.2	0.6	0.13
Copper	6.0	2.0	0.3
Zinc	16	8	10
Manganese	50	50	80
Iron	15	15	15
Nickel	80	7	79
Cadmium	<0.05	<0.05	<0.05
Arsenic	<1	<1	<1

Table B6  
Metal and Nutrient Concentration in the Standard  
Elutriate, Mobile Bay, Ala.

Site	Depth cm	Ammonium-N		Nitrate + Nitrite		Orthophosphate µg/l	Hg µg/l	Cu µg/l	Zn µg/l	Mn mg/l	Fe µg/l	Ni µg/l	Cd µg/l	As µg/l
		µg/l		µg/l										
1	0-15	156		371		<3	0.01	1.0	3.0	2.73	27.5	27.0	0.05	3.65
	15-30	178		31		<3	0.02	1.6	3.6	2.48	55.0	19.0	0.05	2.15
	30-45	151		180		<3	0.01	1.3	5.5	2.05	327.5	30.0	0.05	1.75
	45-60	221		412		<3	0.06	1.7	5.5	2.01	235.0	15.0	0.05	1.95
2	0-15	151		10		<3	0.04	5.7	8.6	1.15	170.0	11.0	0.05	1.20
	15-30	149		89		<3	0.01	1.3	2.2	1.40	87.5	15.5	0.05	0.75
	30-45	118		323		<3	0.03	2.9	4.5	0.73	31.3	10.5	0.05	1.40
	45-60	132		304		<3	0.06	0.4	6.8	0.27	---	25.0	0.05	2.35
3	0-15	109		71		<3	0.08	0.5	5.0	0.74	50.0	325.0	0.05	1.05
	15-30	90		38		<3	0.15	0.5	4.7	0.60	37.5	13.5	0.05	2.05
	30-45	88		36		<3	0.02	1.0	6.0	0.57	20.0	23.5	0.05	1.30
	45-60	96		76		<3	0.04	0.7	7.0	0.65	30.0	15.5	0.05	1.05

Table B7  
Nutrient and Heavy Metal Concentration of Dredging Site Water  
used in the Ashtabula, Ohio, Elutriate Test

Site	$\text{NH}_4^+-\text{N}$ $\mu\text{g/l}$	$\text{NO}_3^-+\text{NO}_2^-$ $\mu\text{g/l}$	Ortho- phosphate $\mu\text{g/l}$	Hg $\mu\text{g/l}$	Cu $\mu\text{g/l}$	Zn $\mu\text{g/l}$	Mn $\mu\text{g/l}$	Fe $\mu\text{g/l}$	Ni $\mu\text{g/l}$	Cd $\mu\text{g/l}$	As $\mu\text{g/l}$
1	807	1400	<1.2	--	3	15	40	5	10.5	3.0	1.1
2	242	583	5.0	--	3	3	2	6	6.0	1.4	0.8
3	140	461	<1.2	--	3	14	1	30	4.0	1.0	1.0
4	303	595	<1.2	--	6	21	1	30	3.0	1.9	1.2
5	152	367	5.0	--	6	12	1	20	5.0	1.7	1.0

Table B8  
Metal and Nutrient Concentration in the Standard Elutriate, Ashtabula, Ohio

Site	Depth cm	$\text{NH}_4^+-\text{N}$ mg/l	$\text{NO}_3^-+\text{NO}_2^-$ µg/l	Ortho- Phosphate µg/l	Hg µg/l	Cu µg/l	Zn µg/l	Mn mg/l	Fe µg/l	Ni µg/l	Cd µg/l	As µg/l
1	0-15	14.65	310	2.2	<0.20	<1	10.0	0.97	25	13.5	<1	3.8
	15-30	14.65	325	1.8	<0.20	<1	140.0	1.03	53	10.5	<1	6.3
	30-45	17.10	295	1.2	<0.20	<1	10.5	0.81	586	35.0	<1	4.1
	45-60	14.50	370	1.2	<0.20	<1	25.0	0.63	355	20.0	<1	3.4
2	0-15	15.85	260	1.8	<0.20	<1	25.0	0.14	1110	45.0	<1	0.9
	15-30	16.60	290	1.2	<0.20	<1	145.0	0.91	25	35.0	<1	2.2
	30-45	14.10	280	1.2	<0.20	<1	35.0	0.52	940	45.0	<1	1.0
	45-60	12.30	250	1.2	<0.20	<1	105.0	0.42	310	25.0	<1	1.7
3	0-15	10.10	190	1.2	<0.20	<1	360.0	0.50	10	20.0	<1	2.1
	15-30	11.60	165	2.5	<0.20	<1	1270.0	0.62	20	20.0	<1	5.7
	30-45	12.30	110	2.5	<0.20	<1	2255.0	0.24	75	10.0	<1	2.8
	45-60	13.95	170	1.2	<0.20	<1	2070.0	0.09	55	15.0	<1	3.9
4	0-15	11.90	65	3.7	0.20	<1	795.0	0.37	20	20.0	<1	2.1
	15-30	14.70	70	1.2	0.20	<1	410.0	0.22	80	30.0	<1	3.1
	30-45	14.30	125	3.1	0.20	<1	2000.0	0.33	620	35.0	<1	1.8
	45-60	14.55	115	1.8	0.35	<1	385.0	0.31	345	35.0	<1	1.7
5	0-15	4.70	75	4.6	0.20	<1	15.0	0.12	5	6.5	<1	4.2
	15-30	9.85	85	3.7	0.20	<1	10.0	0.13	20	12.5	<1	3.9
	30-45	10.90	90	1.8	0.20	<1	415.0	0.15	15	10.0	<1	4.3
	45-60	14.10	75	1.2	0.20	<1	10.0	0.09	10	7.5	<1	4.7

### Nutrient and Heavy Metal Concentration of Eaton's Neck Disposal Water

Concentration, $\mu\text{g}/\ell$										
$\text{NH}_4^+-\text{N}$	$\text{NO}_3^-+\text{NO}_2^-$	Ortho-phosphate	Mn	Zn	Fe	Cm	Cd	Ni	As	Hg
<1.4	5	60	24	14	<10	4	5	3.5	<1	.3

Table B10  
Metal and Nutrient Concentration in the Standard Elutriate, Bridgeport, Conn.

Site	Depth cm	$\text{NH}_4^+-\text{N}$ $\mu\text{g/l}$	$\text{NO}_3^-+\text{NO}_2^-$ $\mu\text{g/l}$	Ortho- phosphate $\mu\text{g/l}$	Hg $\mu\text{g/l}$	Cu $\mu\text{g/l}$	Zn $\mu\text{g/l}$	Mn mg/l	Fe $\mu\text{g/l}$	Ni $\mu\text{g/l}$	Cd $\mu\text{g/l}$	As $\mu\text{g/l}$
1	0-15	23.85	105	106	0.5	19.5	156	0.026	18	7.5	4.0	1.0
	15-30	19.00	120	128	0.5	14.5	314	0.022	12	5.0	5.0	2.5
	30-45	21.65	90	127	0.6	7.5	490	0.017	22	9.5	5.5	6.5
	45-60	17.00	200	81	0.3	6.0	644	0.016	15	9.5	5.0	1.5
2	0-15	12.95	170	82	0.4	12.0	330	0.028	29	6.0	5.0	1.0
	15-30	17.10	170	137	0.3	6.0	724	0.012	24	5.0	5.0	1.0
	30-45	20.35	145	355	0.8	11.0	1285	0.014	17	6.0	5.0	12.5
	45-60	23.05	110	394	0.5	7.5	104	0.018	26	5.0	5.0	5.5
3	0-15	9.80	55	167	0.4	6.5	1620	0.015	125	23.0	4.5	<1.0
	15-30	14.95	130	154	0.6	6.5	836	0.022	315	6.0	4.5	<1.0
	30-45	14.45	80	156	0.5	9.0	800	0.016	61	9.0	5.0	1.0
	45-60	18.30	90	335	1.6	10.0	370	0.032	25	6.5	5.0	3.5
4	0-15	6.30	110	130	4.0	8.5	1840	0.032	21	7.5	5.5	<1.0
	15-30	10.80	125	166	0.6	6.5	975	0.026	61	9.0	4.5	2.5
	30-45	11.05	160	359	0.2	5.5	1900	0.028	28	12.0	4.5	6.5
	45-60	16.00	130	453	0.2	4.0	1650	0.026	27	10.5	4.0	14.5
5	0-15	21.30	60	124	0.2	5.0	3541	0.980	400	15.0	5.0	1.0
	15-30	28.40	155	114	0.1	6.5	3510	0.740	280	10.0	6.5	<1.0
	30-45	29.45	100	111	0.1	3.0	970	0.740	36	6.5	5.0	1.0
	45-60	24.60	100	101	0.2	5.5	560	0.580	46	12.5	4.5	<1.0

Table B11  
Iron Content in Chemical Fractionation of Mobile Bay, Ala. Sediments

Chemical Fraction*	Iron Content Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	0.08	0.21	0.52	0.41	0.06	0.25	0.23	0.19	0.08	0.09	0.09	0.08
Exchangeable	1.27	0.89	2.57	2.08	1.92	1.75	2.13	0.87	0.89	0.93	0.90	0.89
Easily reducible	4.10	5.85	3.73	3.63	4.03	3.89	3.67	3.02	2.28	2.83	2.51	2.28
Organic + sulfide	12.67	10.32	13.36	13.91	13.36	13.26	12.67	19.01	19.41	18.53	20.43	19.41
Moderately reducible	72.75	72.66	71.38	71.22	72.23	72.50	72.74	68.28	68.54	68.89	67.39	68.54
Residual	9.11	7.76	8.34	8.76	8.38	8.35	8.55	8.64	8.79	8.73	8.69	8.79
Total by summation, %	2.80	3.04	2.90	2.81	3.15	3.09	3.11	3.14	3.07	2.97	3.06	3.07
Analytical total, %	4.36	4.96	4.34	4.47	4.08	4.07	3.95	4.18	4.50	4.28	4.60	4.07

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.

Table B12  
Iron Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Iron Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	0.30	0.21	0.20	0.15	0.07	0.07	0.09	0.15	0.13	0.15	0.16	0.21
Exchangeable	2.16	1.71	1.40	1.44	1.38	1.53	1.20	2.05	1.25	1.18	0.90	1.67
Easily reducible	2.69	2.74	1.94	1.54	0.62	0.07	0.28	0.08	0.72	0.72	0.28	0.53
Organic + sulfide	2.91	3.67	4.55	2.25	2.00	2.09	2.65	2.19	3.40	2.32	2.20	2.58
Moderately reducible	31.10	29.43	33.17	32.66	40.14	36.75	44.25	41.57	38.52	34.73	36.37	32.51
Residual	60.84	62.25	58.75	61.96	55.79	59.49	51.52	53.96	55.98	60.90	60.09	62.67
Total by summation, %	3.70	4.08	4.04	4.03	4.26	4.75	4.80	3.74	4.18	4.00	4.14	3.13
Analytical total, %	3.64	3.82	3.92	4.09	4.18	4.40	6.84	4.11	4.27	4.20	4.41	4.14

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.



Table B14  
Manganese Content in Chemical Fractionation  
of Mobile Bay, Ala., Sediments

Chemical Fraction*	Manganese Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	2.03	2.67	2.20	1.14	1.69	1.20	0.97	0.82	0.66	0.70	0.80	0.80
Exchangeable	12.90	13.52	8.86	4.75	15.09	9.92	5.58	4.72	7.22	7.07	7.19	6.59
Easily reducible	35.50	18.50	16.54	37.91	16.78	16.46	15.82	14.79	14.92	13.70	14.90	14.41
Organically bound	35.53	41.86	49.24	37.69	45.29	51.49	56.11	58.99	44.36	47.72	45.91	45.07
Moderately reducible	5.97	7.33	7.04	5.92	8.06	7.92	8.11	7.95	10.74	9.81	9.41	9.59
Residual	8.07	16.12	16.17	12.75	13.09	12.99	13.00	12.73	22.12	20.95	21.79	23.59
Total by summation, %	1069	626	701	926	850	710	724	771	638	588	487	594
Analytical total, ppm	1074	795	696	685	836	890	798	922	599	555	586	522

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.

Table B15  
Manganese Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Manganese Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Interstitial water	1.75	0.99	0.25	0.19	0.23	0.25	0.18	0.35	0.45	0.42	0.35	0.43
Exchangeable	11.90	6.40	2.37	2.33	4.24	4.80	2.78	4.89	4.94	4.05	3.32	4.14
Easily reducible	17.24	17.55	8.52	9.10	14.49	12.62	8.95	9.03	12.76	15.11	14.80	16.83
Organic + sulfide	31.86	35.62	54.44	52.04	40.27	20.11	27.37	33.61	43.43	45.82	54.47	45.31
Moderately reducible	3.87	3.26	2.85	4.77	20.23	40.03	40.11	18.27	10.30	3.90	5.36	5.10
Residual	33.38	36.18	31.55	36.34	20.59	22.19	20.59	33.83	28.11	30.68	21.68	27.89
Total by summation, ppm	538	553	585	612	1044	1037	1112	591	594	600	826	570
Analytical total, ppm	515	495	570	585	765	1185	1180	725	510	560	795	565

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.

Table B16  
Manganese Content in Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Manganese Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Interstitial water, ppm	1.84	1.0	0.74	1.23	0.41	0.02	0.04	0.03	0.25	0.02	0.02	0.25
Exchangeable	1.68	0.77	0.44	1.01	0.29	0.05	0.06	0.04	0.01	0.003	0.004	0.004
Easily reducible	5.93	3.67	3.28	5.32	0.95	1.00	0.94	0.87	0.99	0.70	1.04	0.93
Organic + sulfide	28.52	28.34	27.03	33.70	33.58	30.53	27.04	25.42	20.29	22.03	33.15	26.09
Moderately reducible	4.60	4.40	3.38	3.70	2.64	2.29	2.96	2.88	3.69	3.60	3.93	2.84
Residual	59.28	62.85	65.87	56.34	62.50	66.16	69.03	70.81	75.09	73.75	61.96	70.11
Total by summation, ppm	582	568	542	678	792	786	662	716	542	522	552	552
Analytical total, ppm	530	565	575	505	515	585	580	610	490	470	400	545

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppm).

Table B17  
Copper Content in Chemical Fractionation  
of Mobile Bay, Ala., Sediments

Chemical Fraction *	Copper Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm					
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	1.21	2.26	1.40	1.90	1.97	1.67	2.23	1.27	2.24	2.27	1.33	1.00
Exchangeable	—	—	—	—	—	—	—	—	—	—	—	—
Easily reducible	0.24	4.70	3.61	0.05	0.07	0.09	0.02	0.02	0.05	0.05	0.04	0.04
Organically bound	32.63	32.36	32.50	35.77	39.06	35.82	33.94	32.09	41.71	33.80	28.99	34.77
Moderately reducible	6.11	6.43	6.64	1.80	2.25	3.94	2.52	2.29	13.83	6.90	6.28	12.03
Residual	61.02	56.51	57.25	62.35	58.60	60.13	63.83	65.58	51.41	59.25	64.69	50.95
Total by summation, ppm	37.8	37.0	41.6	37.1	43.5	45.2	45.3	45.7	42.8	40.0	37.9	44.7
Analytical total, ppm	36.3	41.0	35.1	41.5	33.0	33.5	36.7	31.0	41.5	39.0	41.4	39.8

Note: No exchangeable fraction copper was extracted.

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B18  
Copper Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Copper Content, Percent of Total																				
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm				Site 4, Depth, cm				Site 5, Depth, cm				
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	
Interstitial water, ppm	1.3	0.3	0.25	0.25	0.15	0.10	0.15	0.10	0.10	0.10	0.10	0.15	0.10	0.20	0.20	0.15	0.30	0.15	0.30	0.30	0.35
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	0.10	--	0.07	--	0.18	0.20	0.11	0.08	--	--	0.03	0.04	--	0.03	--	0.02	--	--	--	--	--
Organic + sulfide	58.66	67.00	70.03	69.43	61.17	61.29	69.90	69.55	63.42	69.21	64.23	46.12	56.77	42.76	58.58	62.71	51.94	46.61	56.75	57.97	
Moderately reducible	--	--	--	--	1.06	1.76	2.38	--	3.74	4.46	2.78	5.26	6.80	11.04	5.03	8.44	4.70	9.05	9.94	8.19	
Residual	41.24	33.00	29.88	30.57	37.58	36.76	27.54	30.29	32.89	26.25	33.02	48.52	36.56	46.30	36.24	28.81	43.48	44.17	33.44	33.86	
Total by summation, ppm	19.4	26.2	33.3	27.3	43.2	52.2	69.0	48.7	38.0	41.9	37.1	37.1	29.4	29.7	33.8	30.2	25.3	28.3	31.4	44.3	
Analytical total, ppm	31.0	33.5	33.5	33.0	48.5	46.0	70.5	43.0	39.5	41.5	48.5	40.0	37.0	36.0	36.5	31.5	40.5	39.5	37.0	51.0	

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B19  
Copper Content in Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Copper Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	12.5	14	15	11	5.5	5.5	3.5	3.5	4.5	4.5	21	12
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	0.004	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.003	0.004	0.01
Organic + sulfide	91.15	90.95	91.09	89.44	92.99	92.37	87.59	90.83	92.24	92.89	94.17	93.45
Moderately reducible	0.79	0.38	0.30	0.41	0.44	1.02	1.18	0.96	0.31	0.35	0.31	0.21
Residual	8.04	8.60	8.70	10.13	6.59	6.59	11.14	8.28	7.45	6.77	5.56	6.40
Total by summation, ppm	746	729	606	701	842	747	419	785	1430	1420	1869	1390
Analytical total, ppm	515	560	485	560	600	660	476	675	1455	1265	1325	1295

	Copper Content, Percent of Total							
	Site 4, Depth, cm				Site 5, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	8	4.5	5	7.5	7.5	9.5	13.5	10.5
Exchangeable	--	--	--	--	--	--	--	--
Easily reducible	0.002	0.004	0.002	0.004	0.002	0.007	<0.001	<0.001
Organic + sulfide	91.63	92.84	92.69	96.59	92.12	93.10	92.55	92.89
Moderately reducible	0.47	0.26	0.15	0.15	0.29	0.003	0.08	0.00
Residual	7.92	6.95	7.17	3.26	7.62	11.66	7.40	7.11
Total by summation, ppm	1578	1425	1506	1965	1942	2101	2068	2166
Analytical total, ppm	1205	1090	1220	896	1555	2265	1690	2550

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B20  
Zinc Content in Chemical Fractionation  
of Mobile Bay, Ala., Sediments

Chemical Fraction *	Zinc Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm					
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Interstitial water, ppb	35.3	27.3	45.3	40.5	15.7	44.0	34.0	18.0	46.3	26.0	31.3	56.0
Exchangeable	—	—	—	—	—	—	—	—	—	—	—	—
Easily reducible	4.15	2.25	2.98	2.98	3.00	1.37	1.41	1.51	1.81	2.25	1.71	1.28
Organic + sulfide	52.04	51.13	52.22	65.37	67.45	35.28	46.00	50.71	72.18	58.97	67.76	38.03
Moderately reducible	—	—	—	—	—	—	—	—	—	—	—	—
Residual, by difference	43.79	46.60	45.23	31.64	29.54	63.32	52.58	47.77	26.00	38.76	30.51	60.68
Total by summation, ppm	—	—	—	—	—	—	—	—	—	—	—	—
Analytical total, ppm	257	306	248	213	259	375	311	181	149	177	149	188

Note: No exchangeable or moderately reducible zinc was extracted.

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B21  
Zinc Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Zinc Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	0.33	6.08	0.19	0.03	0.11	0.26	0.59	0.76	0.06	0.24	0.02	0.01
Exchangeable	0.21	0.19	0.24	1.70	0.46	1.34	1.19	1.69	--	--	--	--
Easily reducible	8.17	9.55	5.85	8.77	4.79	10.37	2.27	3.12	6.70	6.84	1.44	1.58
Organic + sulfide	52.72	55.97	39.24	17.05	37.59	17.44	21.82	18.57	64.60	58.18	14.30	40.28
Moderately reducible	38.74	30.77	43.77	72.41	16.63	32.79	34.09	13.57	28.61	14.09	28.00	30.97
Residual (by difference)	0	3.45	10.94	0	40.48	39.30	41.82	64.64	0	20.89	56.20	27.16
Total by summation, ppm	--	--	--	--	--	--	--	--	--	--	--	--
Analytical total, ppm	222	377	265	240	415	430	440	560	310	440	1475	720
									360	655	380	310
									285	265	250	480

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.

Table B22  
Zinc Content in Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Zinc Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	0.03	0.05	0.29	0.03	0.15	0.05	0.46	0.06	0.007	0.006	0.11	0.003
Exchangeable	0.06	0.07	0.16	0.62	0.007	1.15	0.05	0.11	0.56	0.18	0.37	0.26
Easily reducible	8.86	10.22	19.67	10.34	11.18	9.43	7.36	12.76	24.81	20.92	24.17	11.91
Organic + sulfide	69.29	35.22	37.56	34.31	52.87	38.44	65.37	68.82	58.17	57.97	69.58	60.03
Moderately reducible	21.85	54.56	42.61	54.74	35.95	50.97	27.26	18.30	16.47	20.92	5.83	27.81
Residual (by difference)	--	--	--	--	--	--	--	--	--	--	--	--
Total by summation, ppm	--	--	--	--	--	--	--	--	--	--	--	--
Analytical total, ppm	480	580	218	435	470	575	670	620	1170	3325	1110	1035

	Zinc Content, Percent of Total							
	Site 4, Depth, cm				Site 5, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water	0.05	0.08	0.09	0.06	0.007	0.007	0.006	0.008
Exchangeable	0.60	0.28	0.71	0.81	0.12	0.16	0.42	0.03
Easily reducible	19.43	12.99	12.16	12.19	16.07	8.33	17.80	11.47
Organic + sulfide	63.71	82.07	81.19	63.35	67.98	35.53	50.39	36.64
Moderately reducible	16.34	4.70	6.00	23.65	10.00	0.00	2.33	0.00
Residual (by difference)	--	--	--	--	5.84	58.00	29.07	51.83
Total by summation, ppm	--	--	--	--	--	--	--	--
Analytical total, ppm	840	980	825	710	890	1500	1135	1935

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column.

Table B23

Nickel Content in Chemical Fractionation  
of Mobile Bay, Ala., Sediments

Chemical Fraction*	Nickel Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	4.5	13.3	1.3	6.3	4.7	10.7	3.7	15.3	51.3	218.0	252.0	430.0
Exchangeable	0.21	0.78	0.12	0.38	1.96	1.52	0.97	0.03	--	--	--	--
Easily reducible	1.35	2.24	4.36	1.59	3.12	0.62	0.84	0.97	1.38	0.84	0.86	1.57
Organically bound	5.40	5.71	6.43	5.00	6.94	6.94	5.76	4.53	7.55	7.22	7.13	8.05
Moderately reducible	--	--	--	--	--	--	--	--	--	--	--	--
Residual	93.56	91.25	89.07	92.41	87.96	90.90	92.40	94.44	91.05	91.93	92.00	90.36
Total by summation, ppm	115.6	116.8	148.7	144.1	126.2	132.5	129.6	130.9	116.0	117.2	124.1	124.8
Analytical total, ppm	148.0	204.8	137.2	141.0	146.1	141.8	147.2	163.3	151.0	166.3	144.5	183.2

Note: No moderately reducible nickel was extracted.

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B24  
Nickel Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Nickel Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Interstitial water, ppb	60	40	25	15	25	35	35	45	50	70	65	45
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	0.82	0.91	1.10	1.05	0.68	0.54	0.54	0.59	1.00	0.82	0.72	0.32
Organic + sulfide	6.79	6.61	11.64	9.33	10.91	7.92	17.25	11.99	9.48	15.59	12.96	9.22
Moderately reducible	23.86	23.17	21.88	21.44	26.45	28.04	26.92	21.08	24.55	21.16	22.57	21.28
Residual	68.55	69.29	65.34	68.21	61.95	63.49	55.29	66.38	65.38	62.23	63.64	68.80
Total by summation, ppm	147	177	169	177	194	240	276	222	200	183	191	203
Analytical total, ppm	117	149	120	194	261	248	290	211	214	193	218	197

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B25

## Nickel Content in Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Nickel Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	17	16.5	8	15.5	6.5	14	12.5	4	22	4	4	4
Exchangeable	0.01	0.02	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.04	0.08	0.02
Easily reducible	1.05	1.51	1.31	1.31	0.46	0.36	0.50	1.04	2.61	2.17	1.41	1.11
Organic + sulfide	17.87	19.74	15.42	14.95	17.86	18.46	12.33	22.40	32.72	30.56	31.59	21.32
Moderately reducible	0.88	0.31	0.57	0.25	0.00	0.00	0.00	0.07	0.42	0.15	0.28	0.00
Residual	80.21	78.45	82.66	83.48	81.69	81.18	87.20	76.51	64.22	67.08	66.63	77.53
Total by summation, ppm	169.8	168.9	156.9	168.9	157.3	153.0	150.8	174.1	247.1	225.1	202.6	173.1
Analytical total, ppm	205	175	145	170	180	170	150	180	260	220	180	195

	Nickel Content, Percent of Total							
	Site 4, Depth, cm				Site 5, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	9.5	6.5	4.5	12	21	16	12.5	20.5
Exchangeable	0.02	0.02	0.02	0.003	0.02	0.09	0.05	0.02
Easily reducible	2.56	1.55	1.17	0.66	2.57	4.04	3.74	1.81
Organic + sulfide	28.68	27.81	21.10	28.93	33.96	36.98	28.39	45.69
Moderately reducible	0.48	0.13	0.14	0.00	0.97	1.77	1.12	1.14
Residual	68.27	70.45	77.56	70.41	62.53	57.12	66.71	51.34
Total by summation, ppm	183.4	155.0	150.2	183.2	216.2	191.7	169.4	178.8
Analytical total, ppm	185	195	205	230	225	320	216	265

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B26  
Cadmium Content in Chemical Fractionation  
of Mobile Bay, Ala., Sediments

Chemical Fraction *	Cadmium Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm					
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Exchangeable	—	—	—	—	—	—	—	—	—	—	—	—
Easily reducible	0.39	0.27	0.50	0.34	1.03	0.83	0.83	0.55	0.55	0.39	1.02	0.61
Organically bound	9.76	8.33	17.81	19.12	20.31	20.29	22.16	17.35	25.34	19.57	21.24	19.92
Moderately reducible	—	—	—	—	—	—	—	—	—	—	—	—
Residual	90.03	91.47	81.91	80.56	78.75	79.10	77.00	82.35	74.30	80.07	77.65	79.71
Total by summation, ppm	5.02	5.16	3.76	3.19	3.20	3.35	3.61	3.40	2.88	2.81	2.73	2.76
Analytical total, ppm	3.10	2.70	4.00	2.60	2.30	3.20	3.10	4.40	4.70	5.00	5.50	2.70

Note: No exchangeable or moderately reducible cadmium was extracted.

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B27  
Cadmium Content in Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Cadmium Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45
Interstitial water, ppb	0.7	0.5	0.6	0.4	0.35	0.5	0.7	2.5	0.4	0.1	0.2	0.05
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	5.37	1.14	3.79	3.40	2.19	3.21	4.45	2.39	1.65	3.28	11.10	5.90
Organic + sulfide	82.23	81.07	84.65	79.59	74.06	71.64	78.83	65.35	75.91	84.58	81.90	58.29
Moderately reducible	--	--	--	--	--	--	--	--	--	--	--	--
Residual	12.40	17.86	11.55	17.01	23.81	25.15	16.77	32.26	22.53	12.21	7.06	35.90
Total by summation, ppm	1.21	1.40	3.03	2.94	7.98	11.53	9.54	8.37	5.77	6.55	7.79	5.85
Analytical total, ppm	5.0	1.5	4.0	1.75	4.5	6.5	6.5	4.0	3.5	5.0	10.5	4.5

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B28  
Cadmium Content in Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Cadmium Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	26	28	27	19	24	24	32	26	25	25	27	27
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	1.86	4.71	2.80	6.14	8.49	9.45	7.36	3.83	5.97	1.85	2.44	5.80
Organic + sulfide	98.13	95.29	97.20	93.85	91.51	90.55	92.64	96.17	94.03	98.14	97.56	94.20
Moderately reducible	--	--	--	--	--	--	--	--	--	--	--	--
Residual	--	--	--	--	--	--	--	--	--	--	--	--
Total by summation, ppm	8.0	7.6	5.3	5.3	4.3	4.8	3.2	12.7	56.8	49.5	37.2	13.1
Analytical total, ppm	9.0	10.0	8.5	7.5	7.0	8.5	7.5	14.5	61.5	64.0	33.5	20.0

	Site 5, Depth, cm			Site 6, Depth, cm			Site 7, Depth, cm			Site 8, Depth, cm		
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	4	5	14	8	14	8	5	4	14	8	5	4
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	4.23	2.78	3.03	5.44	3.36	3.46	5.80	3.46	3.46	3.46	3.46	3.46
Organic + sulfide	97.74	99.02	96.97	94.56	96.64	96.54	94.20	96.54	96.54	96.54	96.54	96.54
Moderately reducible	--	--	--	--	--	--	--	--	--	--	--	--
Residual	--	--	--	--	--	--	--	--	--	--	--	--
Total by summation, ppm	13.3	12.7	15.5	17.3	9.8	11.2	13.1	13.1	11.2	9.8	8.0	6.2
Analytical total, ppm	14.0	11.0	14.5	20.5	14.5	13.0	20.0	20.0	13.0	11.0	9.5	7.0

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B29  
Arsenic Content in Chemical Fractionation of  
Mobile Bay, Ala., Sediments

Chemical Fraction *	Arsenic Content Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm					
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	9.6	7	3	3.7	12.5	3.2	1.1	3.6	8	1.2	0.8	1.6
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	3.94	3.14	3.68	3.45	3.33	4.08	3.27	2.42	2.80	2.90	2.47	1.99
Organic + sulfide	--	--	--	--	--	--	--	--	--	--	--	--
Moderately reducible	96.15	96.86	96.32	96.55	96.67	95.92	96.73	97.58	97.20	97.10	97.53	98.01
Residual	--	--	--	--	--	--	--	--	--	--	--	--
Total by summation, ppm	3.64	3.82	3.80	4.06	4.50	4.41	5.20	5.37	6.42	6.21	6.08	6.52
Analytical total, ppm	4.87	5.30	3.33	3.93	4.63	4.47	5.07	4.37	3.23	3.17	5.30	3.20

\* Any fraction that is expressed in terms other than percent of total is also indicated in this column (e.g., Interstitial water, ppb).

Table B30  
Arsenic Content in the Chemical Fractionation of Ashtabula, Ohio, Sediments

Chemical Fraction*	Arsenic Content, Percent of Total											
	Site 1, Depth, cm			Site 2, Depth, cm			Site 3, Depth, cm			Site 4, Depth, cm		
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	26.3	20.2	24.9	14.5	6.3	7.6	6.2	5.1	4.5	5.8	2.6	2.5
Exchangeable	1.01	0.71	0.79	0.20	0.06	0.03	0.07	0.01	0.17	0.11	0.11	0.07
Easily reducible	1.09	0.64	0.90	0.72	0.35	0.40	0.44	0.44	0.67	0.50	0.46	0.61
Organic + sulfide	--	--	--	--	--	--	--	--	--	--	--	--
Moderately reducible	50.47	53.54	56.69	57.50	70.57	71.52	73.86	62.64	65.78	69.00	72.58	55.67
Residual	47.39	45.16	41.62	41.58	29.05	28.03	25.59	36.91	33.41	30.44	26.88	43.60
Total by summation, ppm	8.44	9.19	10.09	9.86	10.67	11.06	10.94	8.94	8.68	8.87	9.30	6.88
Analytical total, ppm	6.04	5.94	7.65	7.15	11.02	11.70	9.35	5.60	6.45	6.35	6.65	6.20

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

Table B31

Arsenic Content in the Chemical Fractionation of Bridgeport, Conn., Sediments

Chemical Fraction*	Arsenic Content, Percent of Total											
	Site 1, Depth, cm				Site 2, Depth, cm				Site 3, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	25.2	14.2	7.0	32.8	2.4	5.3	7.7	32.8	25.5	35.5	4.5	6.5
Exchangeable	--	--	--	--	--	--	--	--	--	--	--	--
Easily reducible	1.09	1.72	0.89	0.69	1.81	3.64	3.04	2.82	0.07	1.07	1.02	1.07
Organic + sulfide	--	--	--	--	--	--	--	--	--	--	--	--
Moderately reducible	86.24	85.22	81.98	87.50	76.21	60.04	52.17	61.13	64.94	66.67	72.06	65.24
Residual	12.66	13.05	17.26	11.90	22.07	36.42	44.93	36.05	34.36	32.26	26.98	33.77
Total by summation, ppm	4.5	4.0	3.9	5.0	5.8	4.5	3.4	3.1	7.1	7.4	8.3	6.0
Analytical total, ppm	5.0	4.6	3.7	6.8	4.1	5.9	4.8	7.5	8.6	7.1	7.0	6.9

	Arsenic Content, Percent of Total							
	Site 4, Depth, cm				Site 5, Depth, cm			
	0-15	15-30	30-45	45-60	0-15	15-30	30-45	45-60
Interstitial water, ppb	4.5	4.0	26	14	129	132	148	33.5
Exchangeable	--	--	--	--	--	--	--	--
Easily reducible	2.17	2.73	1.99	3.50	0.88	1.05	1.38	0.70
Organic + sulfide	--	--	--	--	--	--	--	--
Moderately reducible	63.94	57.81	70.09	60.75	68.70	85.30	71.58	71.43
Residual	33.89	39.45	27.98	35.84	30.50	13.70	27.04	27.93
Total by summation, ppm	5.9	6.5	7.7	5.8	6.2	10.9	9.4	9.3
Analytical total, ppm	5.7	7.0	7.4	10.2	5.6	12.2	9.2	8.8

\* Any fraction that is expressed in terms other than percent of total is so indicated in this column (e.g., Interstitial water, ppb).

APPENDIX C: STATISTICS

Table C1

F-Values from the Analysis of Variance of Some Physical and  
Chemical Characteristics of Mobile Bay, Ala., Sediments

Parameter	Source of Variation		
	Site	Depth	Depth × Site
% solid phase	9.589*	70.126**	2.518
% liquid phase	8.884*	61.901**	2.748*
<2μm fraction	12.272**	6.595*	2.129
2-50μm fraction	1.711	4.131	1.702
>50μm fraction	6.755*	5.308*	5.405**
Total sulfides	7.919*	2.703	2.079
Cation exchange capacity	1.865	2.515	1.185
Total organic carbon	33.804**	2.245	1.787
Inorganic carbon	3.205	0.610	0.055
TKN	--	--	--

\* P < 0.05.

\*\* P < 0.01.

Table C2  
F-Values from the Analysis of Variance of Some Physical and  
Chemical Characteristics of Ashtabula, Ohio, Sediments

Parameter	Source of Variation		
	Site	Depth	Depth x Site
% solid phase	202.161**	0.308	0.838
% liquid phase	202.161**	0.308	0.838
<2 $\mu$ m fraction	12.163**	2.141	1.260
2-50 $\mu$ m fraction	24.215**	1.388	1.303
>50 $\mu$ m fraction	2.326	2.289	1.615
Total sulfides	74.093**	0.668	0.224
Cation exchange capacity	--	--	--
Total organic carbon	17.645**	3.133	1.559
Inorganic carbon	1.648	1.054	1.022
TKN	--	--	--

\*\* P < 0.01.

Table C3

F-Values from the Analysis of Variance of Some Physical and  
Chemical Characteristics of Bridgeport, Conn., Sediments

Parameter	Source of Variation		
	Site	Depth	Depth × Site
% solid phase	3.936	1.436	0.538
% liquid phase	3.936	1.436	0.538
<2μm fraction	6.610*	4.624*	1.024
2-50μm fraction	3.653	4.342*	2.213
>50μm fraction	1.526	1.284	2.581*
Total sulfides	26.410**	5.719*	1.894
Cation exchange capacity	--	--	--
Total organic carbon	12.156**	1.172	0.439
Inorganic carbon	1.043	0.561	0.808
TKN	--	--	--

---

\* P < 0.05.

\*\* P < 0.01.

Table C4

Summary of F-Values from the Analysis of Variance of Nutrient Data

Location	Variable Identification	Source of Variation		
		Site	Depth	Depth x Site
Mobile Bay	Interstitial water $\text{NH}_4^+-\text{N}$	344.148*	1.804	1.565
	KCl extractable $\text{NH}_4^+-\text{N}$	44.220*	3.281	2.212
	Elutriate $\text{NH}_4^+-\text{N}$	85.585*	6.409*	5.635**
	Interstitial water $\text{H}_2\text{PO}_4$	9.259**	7.598**	2.402
	Elutriate $\text{H}_2\text{PO}_4$	--	--	--
Ashtabula	Interstitial water $\text{NH}_4^+-\text{N}$	28.889*	68.229*	13.508*
	KCl extractable $\text{NH}_4^+-\text{N}$	23.775*	4.291**	1.114
	Elutriate $\text{NH}_4^+-\text{N}$	4.151**	1.246	--
	Interstitial water $\text{H}_2\text{PO}_4$	18.522**	14.721**	3.265**
	Elutriate $\text{H}_2\text{PO}_4$	2.446	2.454	--
Bridgeport	Interstitial water $\text{NH}_4^+-\text{N}$	4.213	1.431	1.008
	KCL extractable $\text{NH}_4^+-\text{N}$	0.773	2.844	0.665
	Elutriate $\text{NH}_4^+-\text{N}$	11.705*	2.262	--
	Interstitial water $\text{H}_2\text{PO}_4$	23.611*	1.619	0.739
	Elutriate $\text{H}_2\text{PO}_4$	2.914	3.203	--

\*  $P < 0.05$ .\*\*  $P < 0.01$ .

Table C5  
F-Values from Analysis of Variance for Sediments  
from Mobile Bay, Ala.

Chemical Fraction	Source of Variation		
	Site	Depth	Depth x Site
<u>Iron</u>			
Interstitial water	63.074**	20.331**	9.814**
Exchangeable	12.004**	15.681**	14.074**
Easily reducible	13.628**	3.728	0.535
Organic + sulfide	6.066*	0.871	0.451
Moderately reducible	1.243	0.223	0.338
Residual	9.029*	1.725	0.241
Total	1.807	0.359	1.143
Elutriate test	94.435**	12.867**	66.385**
<u>Manganese</u>			
Interstitial water	18.211**	14.313**	4.922**
Exchangeable	--	--	--
Easily reducible	15.051**	15.039**	10.524**
Organic + sulfide	3.357	0.493	0.786
Moderately reducible	0.395	6.439*	0.371
Residual	8.887*	1.094	0.228
Total	26.434**	1.352	1.866
Elutriate test	9.862**	0.683	0.207
<u>Copper</u>			
Interstitial water	0.043	0.408	0.715
Exchangeable	--	--	--
Easily reducible	1.182	1.628	0.652
Organic + sulfide	2.720	4.194*	6.598**
Moderately reducible	3.348	0.375	1.647
Residual	4.266	2.304	0.624
Total	1.493	0.510	0.567
Elutriate test	2.147	0.910	1.005
<u>Zinc</u>			
Interstitial water	0.174	1.634	1.326
Exchangeable	--	--	--
Easily reducible	53.101**	19.471**	2.038

(Continued)

\* P < 0.05.  
\*\* P < 0.01.

Table C5 (Concluded)

Chemical Fraction	Source of Variation		
	Site	Depth	Depth x Site
<u>Zinc (Continued)</u>			
Organic + sulfide	1.812	2.442	1.276
Moderately reducible	--	--	--
Residual	--	--	--
Total	8.655*	2.069	1.598
Elutriate test	0.299	0.536	0.981
<u>Nickel</u>			
Interstitial water	2.348	0.944	0.899
Exchangeable	11.903**	1.395	1.455
Easily reducible	0.498	0.649	1.547
Organic + sulfide	0.316	0.370	2.959**
Moderately reducible	--	--	--
Residual	1.690	2.730	0.784
Total	0.207	1.304	1.113
Elutriate test	0.597	0.354	0.706
<u>Cadmium</u>			
Interstitial water	--	--	--
Exchangeable	--	--	--
Easily reducible	2.263	1.345	0.247
Organic + sulfide	1.338	1.341	1.259
Moderately reducible	--	--	--
Residual	3.927	3.027	3.622*
Total	1.001	1.483	0.922
Elutriate test	--	--	--
<u>Arsenic</u>			
Interstitial water	0.587	4.080*	0.356
Exchangeable	--	--	--
Easily reducible	0.993	0.888	1.054
Organic + sulfide	--	--	--
Moderately reducible	6.874*	0.942	0.649
Residual	--	--	--
Total	42.516**	0.981	2.414
Elutriate test	1.632	0.343	2.300

\* P &lt; 0.05.

\*\* P &lt; 0.01.

Table C6  
F-Values from Analysis of Variance for Sediments  
from Ashtabula, Ohio

Chemical Fraction	Source of Variation		
	Site	Depth	Depth x Site
<u>Iron</u>			
Interstitial water	30.008**	0.768	7.199**
Exchangeable	29.533**	1.165	1.620
Easily reducible	110.801**	1.002	0.583
Organic + sulfide	295.002**	1.665	1.495
Moderately reducible	3.659	1.240	0.711
Residual	0.569	0.468	--
Total	15.323**	2.319	1.558
Elutriate test	3.051	1.760	--
<u>Manganese</u>			
Interstitial water	19.393**	35.971**	17.598**
Exchangeable	43.918**	8.536**	2.885**
Easily reducible	9.928*	2.496	1.993
Organic + sulfide	7.047*	1.062	0.857
Moderately reducible	350.281**	1.566	1.443
Residual	12.778**	1.616	--
Total	3.819	11.178**	5.462**
Elutriate test	10.560**	1.970	--
<u>Copper</u>			
Interstitial water	1.287	0.683	1.090
Exchangeable	--	--	--
Easily reducible	2.664	0.380	0.591
Organic + sulfide	12.056*	5.727**	2.701*
Moderately reducible	2.483	1.683	1.489
Residual	23.210**	1.165	2.677*
Total	221.831**	2.020	1.877
Elutriate test	--	--	--
<u>Zinc</u>			
Interstitial water	0.858	0.300	1.148
Exchangeable	--	--	--
Easily reducible	1.079	1.249	0.831

(Continued)

\* P < 0.05.  
\*\* P < 0.01.

Table C6 (Concluded)

Chemical Fraction	Source of Variation		
	Site	Depth	Depth x Site
<u>Zinc (Continued)</u>			
Organic + sulfide	3.659	0.408	0.886
Moderately reducible	1.079	1.551	2.219
Residual	--	--	--
Total	3.676	3.300	3.745
Elutriate test	7.703**	2.276	--
<u>Nickel</u>			
Interstitial water	0.784	0.999	0.982
Exchangeable	--	--	--
Easily reducible	14.368**	1.989	0.719
Organic + sulfide	5.664*	3.919*	1.611
Moderately reducible	4.039	1.682	0.937
Residual	3.910	1.199	0.677
Total	3.238	0.135	1.166
Elutriate test	8.146**	0.774	--
<u>Cadmium</u>			
Interstitial water	1.552	0.759	0.874
Exchangeable	--	--	--
Easily reducible	2.225	1.434	0.743
Organic + sulfide	6.909*	1.346	0.914
Moderately reducible	--	--	--
Residual	20.797**	0.749	0.538
Total	7.880*	1.659	2.221
Elutriate test	--	--	--
<u>Arsenic</u>			
Interstitial water	14.899**	14.835**	7.045**
Exchangeable	3.391	4.812*	1.770
Easily reducible	24.878**	3.330*	3.055*
Organic + sulfide	--	--	--
Moderately reducible	7.417*	1.792	0.916
Residual	2.820	0.624	0.831
Total	6.444*	0.183	2.504*
Elutriate test	11.269**	4.552*	--

\* P &lt; 0.05.

\*\* P &lt; 0.01.

Table C7  
F-Values from Analysis of Variance for Sediments  
from Bridgeport, Conn.

<u>Chemical Fraction</u>	<u>Source of Variation</u>		
	<u>Site</u>	<u>Depth</u>	<u>Depth × Site</u>
<u>Iron</u>			
Interstitial water	1.216	0.262	0.850
Exchangeable	--	--	--
Easily reducible	23.473**	3.265*	1.614
Organic + sulfide	2.395	1.112	1.778
Moderately reducible	1.275	0.285	1.030
Residual	2.193	0.155	0.851
Total	2.832	1.454	0.950
Elutriate test	2.940	1.995	--
<u>Manganese</u>			
Interstitial water	31.057**	1.404	0.747
Exchangeable	54.639**	1.042	0.591
Easily reducible	65.518**	1.004	0.495
Organic + sulfide	2.110	1.105	1.031
Moderately reducible	1.188	0.301	0.721
Residual	4.544	0.842	0.730
Total	0.625	3.507*	1.499
Elutriate test	85.377**	1.270	--
<u>Copper</u>			
Interstitial water	1.591	1.662	1.342
Exchangeable	--	--	--
Easily reducible	1.879	0.711	1.512
Organic + sulfide	7.666*	0.009	0.295
Moderately reducible	1.446	1.631	1.177
Residual	8.869*	0.310	0.572
Total	4.247	0.268	0.537
Elutriate test	2.655	1.212	--
<u>Zinc</u>			
Interstitial water	2.274	5.096*	1.560
Exchangeable	1.218	0.104	1.597
Easily reducible	5.402*	1.147	1.393
(Continued)			

\* P < 0.05.

\*\* P < 0.01.

Table C7 (Concluded)

Chemical Fraction	Source of Variation		
	Site	Depth	Depth x Site
<u>Zinc (Continued)</u>			
Organic + sulfide	--	--	--
Moderately reducible	1.474	1.132	0.742
Residual	--	--	--
Total	1.860	1.392	1.646
Elutriate test	3.089	0.916	--
<u>Nickel</u>			
Interstitial water	3.350	1.625	1.188
Exchangeable	11.224**	1.817	1.108
Easily reducible	14.998**	2.655	1.441
Organic + sulfide	22.645	1.816	1.057
Moderately reducible	12.690**	0.664	0.396
Residual	3.392	1.383	0.901
Total	2.543	3.084	1.754
Elutriate test	1.365	1.212	--
<u>Cadmium</u>			
Interstitial water	--	--	--
Exchangeable	--	--	--
Easily reducible	7.718*	4.235*	4.844**
Organic + sulfide	33.576**	2.070	1.864
Moderately reducible	--	--	--
Residual	--	--	--
Total	19.754**	7.937**	5.772**
Elutriate test	0.634	0.457	--
<u>Arsenic</u>			
Interstitial water	16.526**	0.528	1.645
Exchangeable	--	--	--
Easily reducible	2.515	3.052	1.033
Organic + sulfide	--	--	--
Moderately reducible	9.509*	0.357	0.982
Residual	52.504**	0.658	1.641
Total	2.561	1.558	0.960
Elutriate test	2.067	2.729	19.234**

\* P &lt; 0.05.

\*\* P &lt; 0.01.



Table C8 (Concluded)

	Organically Bound				Total Zn	Particle-Size Fraction		Percent Solid Phase		Percent Liquid Phase		Interstitial Water Orthophosphate
	Fe	Cu	Mn	Cd		< 2- $\mu$ m	< 50- $\mu$ m	Percent Solid Phase	Percent Liquid Phase			
Elutriate Fe												
Elutriate Mn												
Elutriate Ni												
Elutriate $\text{NH}_4^+$								0.518*				
Interstitial water Fe								0.730**				
Interstitial water Mn												
Interstitial water $\text{NH}_4^+$							0.757**	0.663**	-0.656**			0.623**
Exchangeable Fe												
Exchangeable Mn												
Exchangeable $\text{NH}_4^+$						-0.583**	0.528**	0.696**	-0.684**			
Easily reducible Mn												
Easily reducible Fe												
Easily reducible Zn												
Easily reducible Ni												
Organically bound Fe		0.731**										
Organically bound Cu				0.489**								
Organically bound Ni			0.499**									
Organically bound Mn				0.499**								
Organically bound Cd		0.489**										
Moderately reducible Fe												
Moderately reducible Mn												
Total Mn												
Total Zn												
Total S <sup>=</sup>							0.524**					
Total organic carbon	0.750**	0.656**					0.613**	-0.616**				

\*  $P < 0.05$ .\*\*  $P < 0.01$ .

Table C9  
Significant Correlation Coefficients of Ashtabula, Ohio, Data

	Elutriate Test					Interstitial Water					Exchangeable				
	Fe	Mn	NH <sub>4</sub> <sup>+</sup>	H <sub>2</sub> PO <sub>4</sub>	As	Fe	Mn	Cu	NH <sub>4</sub> <sup>+</sup>	H <sub>2</sub> PO <sub>4</sub>	Fe	Mn	Zn	NH <sub>4</sub> <sup>+</sup>	As
Total Sulfide															
Elutriate test	Fe														
	Mn														
	NI														
	NH <sub>4</sub> <sup>+</sup>														
Interstitial water	H <sub>2</sub> PO <sub>4</sub>														
	Fe														
	Mn														
	NH <sub>4</sub> <sup>+</sup>														
	H <sub>2</sub> PO <sub>4</sub>														
Exchangeable	As														
	Fe														
	Mn														
	NH <sub>4</sub> <sup>+</sup>														
	Zn														
Easily reducible	As														
	Fe														
	Mn														
	Zn														
Organic + sulfide	NI														
	Fe														
	Cu														
	NI														
	Mn														
	Cd														
Moderately reducible	Fe														
	Mn														
Residual	NI														
	Cu														
	Cd														
Total	Cd														
	NI														
	As														
TEN															

0.453\*\*

0.419\*\*

0.731\*\*

0.659\*\*

0.429\*\*

0.738\*\*

0.533\*\*

0.374\*

0.464\*\*

0.638\*\*

0.489\*\*

0.639\*\*

0.477\*\*

0.639\*\*

0.618\*\*

0.665\*\*

0.660\*\*

0.573\*\*

0.618\*\*

0.547\*\*

0.596\*\*

(Continued)

(Continued)

\* P < 0.05.  
\*\* P < 0.01.

Table C9 (Continued)

[illegible]

(Continued)

\*  $P < 0.05$ .  
\*\*  $P < 0.01$ .

(Sheet 2 of 3)

Table C9 (Concluded)

	Total				1/2 Solid Phase	2- to 50-µm Diameter Fraction	<2-µm Diameter Fraction
	Cd	Cu	Mn	Zn			
Elutriate test							
Fe							
Mn							
NI							
NH <sub>4</sub> <sup>+</sup>							
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>							
Interstitial water							
Fe							
Mn							
NH <sub>4</sub> <sup>+</sup>							
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>							
As					0.636**	0.615**	
Exchangeable							
Fe							
Mn							
NH <sub>4</sub> <sup>+</sup>							
Zn							
As							
Easily reducible							
Fe							
Zn							
NI							
Organic + sulfide							
Fe							
Cu							
NI							
Mn							
Cd							
Moderately reducible							
Fe							
Mn							0.566**
NI							
Cu							
Residual							
Cd							0.575**
Total							
Cd	0.459**		0.481**	0.668**			
NI	0.528**						
As			0.738**				
TKN							

\*\* P &lt; 0.01.

Table C10  
Significant Correlation Coefficients of Bridgeport, Conn., Data

		Elutriate Test				Interstitial Water				Exchangeable			
		Total Sulfide	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	Fe	Mn	NH <sub>4</sub> <sup>+</sup>	Ni	Fe	Mn	NH <sub>4</sub> <sup>+</sup>	Fe	Mn	Ni
Elutriate test	Fe	0.517**	0.763**										
	Mn	0.621**	0.438**										
	Ni						0.394**						
Interstitial water	Cu												
	Fe							0.614**					
	Mn								0.617**				
Exchangeable	NH <sub>4</sub> <sup>+</sup>												
	As	0.587**											
	Fe												
Easily reducible	Mn												
	Ni	0.516**											
	Fe	0.789**											0.575**
Organic + sulfide	Zn	0.471**											0.463**
	Ni	0.826**											
	Cu												
Moderately reducible	Fe	0.677**											0.472**
	Cu	0.685**											
	Ni	0.501**											
Residual	Cd	0.526**											
	Fe												
	Mn												
Total	Ni	0.655**											
	As												
	Cd	0.455**											
Total organic carbon	Cu	0.695**											
	Ni	0.549**											
	Fe	0.496**											

(Continued)

\* P < 0.05.  
\*\* P < 0.01.

Table C10 (Concluded)

	Elutriate test			Easily Reducible			Organic + Sulfide			Moderately Reducible			Total Organic Carbon	
	Mn	Fe	Zn	Ni	Cd	Fe	Cu	Ni	Mn	Cd	Fe	Ni	As	Total As
Elutriate test	Fe	0.513**												
	Mn													
	Ni			0.410*										
	NH <sub>4</sub> <sup>+</sup>													
	Cu													
Interstitial water	Fe													
	Mn	0.806**												
	NH <sub>4</sub> <sup>+</sup>													
	As		0.582**											
	Fe													0.637**
Exchangeable	Mn	0.425**												
	NH <sub>4</sub> <sup>+</sup>													
	Ni													
	Fe													
	As													0.561**
Easily reducible	Mn													
	Fe													
	Zn		0.482**											
	Ni		0.507**											
	Cu													
Organic + sulfide	Fe													
	Cu													
	Ni													
	Mn													
	Cd													
Moderately reducible	Fe													
	Mn	0.482**												
	Ni													
	As													
	Fe													
Residual Total	Cd													
	Cu													
	Ni													
	Fe													
	As													
Total organic carbon	Fe													
	Cd													
	Cu													
	Ni													
	Fe													

\* P < 0.05.  
 \*\* P < 0.01.



Table C11 (Continued)

[illegible]

(Continued)

(Sheet 2 of 3)

Table C11 (Continued)

	Moderately Reducible			Total			<2- $\mu$ m Particle Size Diameter	Total Organic Carbon
	Mn	Ni	Fe	Cd	Mn	Cu		
Interstitial water								
Fe								
Mn					0.467**			
As								
Zn								
Cu								
NH <sub>4</sub> <sup>+</sup>								
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>								
Exchangeable								
Fe								
Mn					0.547**			
Zn								
As								
NH <sub>4</sub> <sup>+</sup>								
Easily reducible								
Mn					0.655**			
Fe								
Zn								
Ni								
As								
Cu								
Organic + sulfide								
Fe								0.405**
Cu								0.418**
Ni								
Mn								
Cd								
Zn								
Moderately reducible	0.213*						0.608**	
Fe								
Mn		0.561**		0.268*				
As		0.366**		0.315*				
Total								
Fe						0.416**		0.503**
Zn						0.649**		0.381**
Cu				0.588**				0.337**
As				0.628**				0.481**
<2- $\mu$ m diameter particle size TKN								0.429**

\* P &lt; 0.05.

\*\* P &lt; 0.01.

Table C12  
Coefficient of Variation for Laboratory Replication of  
the Extractions in Sediments from Mobile Bay, Ala.

Extraction	Coefficient of Variation, %						
	Fe	Mn	Cu	Zn	Ni	Cd	As
Interstitial water	30.4	21.1	59.3	45.15	187.3	--	104.64
Ammonium acetate	7.0	--	--	--	--	--	--
Hydroxylamine hydrochloride	8.8	9.7	126.5	12.4	196.1	69.32	25.85
Acidified H <sub>2</sub> O <sub>2</sub>	14.0	15.9	7.4	24.3	22.7	24.9	--
Citrate-dithionite	9.9	10.7	68.9	--	--	--	26.66
Residual	4.6	22.3	14.4	28.2(T)*	15.71	40.4	16.78
Elutriate test	20.8	63.5	119.4	57.2	69.17	--	40.23

\* T = total digest.

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